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THE

COMBUSTION OF COAL

AND THE

PREVENTION OF SMOKE

CHEMICALLY

AND

PRACTICALLY CONSIDERED.

BY C. W. WILLIAMS, ESQ.,
ASSOC. INST. C. E.,
&c. &c. &c.

WITH NUMEROUS ILLUSTRATIONS.

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DEDICATION.

TO THE

RIGHT HON. LORD VISCOUNT PALMERSTON, M.P.,

SECRETARY OF STATE FOR THE HOME
DEPARTMENT.

My Lord,

Your Lordship having kindly assented to my work on "The Combustion of Coal and the Prevention of Smoke, Chemically and Practically Considered," being dedicated to your Lordship, I now submit it, in respectful acknowledgment of the services conferred on the public by your Lordship's Act, making the abatement of the smoke nuisance *compulsory*.

This work, my Lord, is the result of my practical experience as Founder and Managing Director of the City of Dublin Steam Packet Company, established in 1824. In it I have not made a single statement that has not been either warranted by the highest chemical authorities, or justified by the most unquestionable experimental proof.

As considerable alarm has been expressed by certain manufacturers and others, under the impression that from the nature of their respective operations, it will be impossible to comply with the provisions of the Act (16 & 17 Vict. cap. 128), I may here observe, that although many have been induced to adopt complicated, and even costly expedients, and have, nevertheless, failed in preventing the nuisance so justly complained of, they may yet find, that by more correct, simple, and less expensive means, they may be enabled to satisfy the exigencies of that Act.

During the last fifteen years I have proved, that even in the largest establishments, and in the furnaces of marine boilers, the great nuisance of smoke may be avoided, and even with the accompaniment of considerable economy.

Although many hundreds of furnaces in the manufacturing districts have been constructed by others, on the principles suggested in this work, I have never made a single application to any government or public establishment; aware of the suspicion which ever attaches to the advocacy of an interested party; and, above all, of the difficulty of overcoming old-established customs and prejudices. I have long, therefore, anxiously looked for some legislative enactment by which those who create public nuisances shall be compelled to abate them.

My patent of 1839 having now expired, I have no interest whatever in bringing the subject thus prominently forward, beyond the natural claim to the credit of having (in the words of Sir Robert Kane) been "the first to place this subject in its important and just aspect."

I have the honor to be,

My Lord,

Your Lordship's obliged and humble Servant,

CHARLES WYE WILLIAMS.

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PREFACE.

Being much interested in the improvement of steam vessels, from my connection with several steam navigation companies, and having had a longer and more extended experience in the details of their building and equipping than, perhaps, any individual director of a steam company in the kingdom, my attention has been uninterruptedly given to the subject since the year 1823, when I first established a steam company, and undertook to have the first steam-vessel constructed capable of maintaining a commercial intercourse across the Irish Channel, during the *winter* months, and which, till then, had been considered impracticable.

The result of this long experience is the finding, that, notwithstanding the improved state to which the construction and appointments of the hull and general machinery of steam-vessels have arrived, great uncertainty and risk of failure still prevail in the *use of fuel* and the *generation of steam.*

It is true, the engineer, who undertakes the construction of the engines, also undertakes that the boilers shall provide a sufficiency of steam to work them; but what that *sufficiency* means, has not been decided; and, in too many instances, the absence of some fixed data on the subject leaving the evils of a deficiency of steam or a great expenditure of fuel unabated.

So long as the operations of steam-vessels were confined to coasting or short voyages, the consequences of these defects in boilers, as regards the quantity of fuel, were a mere question of pounds, shillings, and pence. When, however, those operations came to be extended to long sea voyages, these consequences took a more comprehensive range, and involved the more important question, whether such voyages *were practicable* or profitable.

From being so deeply interested in the improvement of this department of steam navigation, I have watched, with no small anxiety, the efforts of the engineers to arrive at some degree of certainty in what was admitted, on all hands, to be the most serious drawback to the successful application of steam-vessels to long sea voyages. I perceived the absence of any well-founded principle in the construction of the boiler;—that the part on which most depended appeared least understood, and least attended to, namely, the *furnace;* and that this was too often left to the skill (or want of it) of working boiler-makers or bricklayers. I saw that, although the great operations of combustion carried on in the furnace, with all that belongs to the introduction and employment of atmospheric air, were among the most difficult processes within the range of chemistry, the absence of sound scientific principles still continued to prevail; yet on these must depend the extent or perfection of the combustion in our furnaces.

Years were still passing away, and while every other department was fast approaching to perfection, all that belonged to the combustion of fuel—the production of smoke—and the wear and tear of the furnace part of the boiler, remained in the same *status quo* of uncertainty and insufficiency; and even that boilers and their furnaces, constructed within the last few years, exhibit greater violations of chemical truths, and a greater departure from the principles on which nature proceeds, than any preceding ones which have come under my observation.

In the proper place I will shew, that, of late years, as much uncertainty as to the success of a new boiler has prevailed as when I first began operations, thirty years ago; and that few boilers, for land or marine engines, exhibit more in the way of effecting perfect combustion or economy of fuel than those of any former period since the days of Watt.

I here observe, that I do not affect to give any new view of the nature of combustion, much less do I make any claim to discovery. What I take credit for is, the practical application, *on the large scale of the furnace,* of those chemical truths which are so well known in every *laboratory.* I also take credit for bringing together the scattered facts and illustrations of such authorities as bear on the subject before us, and so applying them as to enable practical men to understand that part which chemistry has to act in the construction, arrangements, and working of our boilers and furnaces.

The first part of this Treatise, in which the chemistry of combustion is considered, first published in 1840, is here now republished in a condensed form, in connexion with the second part, involving the practical application of the subject.

It is here unnecessary to say any thing on the causes which have led to so long an interval. It may, however, be observed, that the postponement of the second or practical part, has had this advantage, that it has afforded the means of introducing the recent changes that have been made in boilers; and particularly of that important one, the introduction of the *tubular* principle into steam navigation.

C. W. WILLIAMS.

Liverpool,
1854.

PART FIRST.

CHAPTER I.

OF THE CONSTITUENTS OF COAL, AND THE GENERATION OF COAL GAS.

In the following treatise I do not undertake to shew how *the smoke* from coals can be *burned;* but I do undertake to shew how *coals may be burned without smoke;* and this distinction involves the main question of economy of fuel.

When smoke is once produced in a furnace or flue, it is as impossible to burn it or convert it to heating purposes, as it would be to convert the smoke issuing from the flame of a candle to the purposes of heat or light.

When we see smoke issuing from the flame of an ill-adjusted common lamp, we also find the flame itself dull and murky, and the heat and light diminished in quantity. Do we then attempt to *burn that smoke?* No; it would be impossible. Again, when we see a well-adjusted Argand lamp burn *without producing any smoke,* we also see the flame white and clear, and the quantity of heat and light increased. In this case, do we say the lamp *burns its smoke?* No; we say the lamp *burns without smoke.* This is the fact, and it remains to be shewn why the same language may not be applied to the combustion of the same coal and the same gas, in the *furnace,* as in the *lamp.*

In a treatise purporting to describe the means of obtaining the largest quantity of heat from coal, the first step is an inquiry into the varieties of that combustible and its respective constituents.

The classification of the various kinds of coal, the details of an elaborate analysis, made by Mr. Thomas Richardson, with the aid of Professor Liebig are as follows: —

Species of Coal.	Locality.	Carbon.	Hydrogen.	Azote and Oxygen.	Ashes.
Splint . .	Wylam . .	74·823	6·180	5·085	13·912
,, . .	Glasgow .	82·924	5·491	10·457	1·128
Cannel . .	Lancashire .	83·753	5·660	8·039	2·548
,, . .	Edinburgh .	67·597	5·405	12·432	14·566
Cherry . .	Newcastle .	84·846	5·048	8·430	1·676
,, . .	Glasgow .	81·204	5·452	11·923	1·421
Caking . .	Newcastle .	87·952	5·239	5·416	1·393
,, . .	Durham .	83·274	5·171	9·036	2·519

The most important feature in reference to this analysis, is the proportion of hydrogen which all bituminous coal contains, and which may be estimated at 5½ per cent — hydrogen being the main element in the evolved gas, and by the combustion of which flame is produced.

The theory of combustion is now well understood by scientific men; but, as a *practical art,* it still remains at a very low ebb.

We know, *scientifically,* that carburetted hydrogen and the other compounds of carbon require given quantities of atmospheric air to effect their combustion; yet we adopt no means, *practically,* of ascertaining what *quantities* are supplied, and treat them as though no such proportions were necessary. We know, *scientifically,* the relative proportions in which the constituents of atmospheric air are combined; yet, *practically,* we appear wholly indifferent to the distinct nature of these constituents, or their effects in combustion. We know, *scientifically,* that the inflammable gases are combustible only in proportion to the *degree of mixture* which is effected between them and the oxygen of the air; yet, *practically,* we never trouble our heads as to whether we have effected such mixture or not. These and many similar illustrations exhibit a reprehensible degree of carelessness, which can only be corrected by a sounder and more scientific knowledge of the subject; and this can only be attained *through the aid of chemistry.*

The main constituents of all coal, as we see in the preceding table, are *carbon* and *hydrogen.*

In the natural state of coal, the hydrogen and carbon are united and solid. Their respective characters and modes of entering into combustion are, however, essentially different; and to our neglect of this primary distinction is referable much of the difficulty and complication which attend the use of coal on the large scale of our furnaces.

The first leading distinction is, that the bituminous portion is convertible to the purposes of heat in the *gaseous state alone;* while the carbonaceous portion, on the contrary, is combustible *only in the solid state;* and, what is essential to be borne in mind, *neither can be consumed while they remain united.*

The use of the term "*fuel,*" as applied to the combustion of coal during its several processes in the furnace, without reference to any particular constituent, whether gaseous or solid, is sufficiently indicative of the inattention to the chemical conditions of combustion.*

The general impression is, that coal, spoken of under the objectionable term of "*fuel,*" enters into combustion *at once,* on the application of heat, and that, *during such combustion,* it evolves the gaseous matter which it contains. This, however, is neither correct nor scientific, and evades an important feature in the use of coal, namely, *the order* in which the gaseous and solid portions come into use as heat-giving media.

When heat is first applied to bituminous coal, the question naturally arises, What becomes of it? or, What is its effect?

A charge of fresh coal thrown on a furnace in an active state, so far from augmenting the general temperature, becomes at once an *absorbent* of it and the source of the *volatilization* of the bituminous portion of the coal; in a word, of the generation of the gas. Now, volatilization is the most cooling process of nature, by reason of the quantity of heat which is directly converted from the *sensible* to the *latent* state. So long as any of the bituminous constituents remain to be evolved from any atom or division of the coal, its solid, or carbonaceous part remains black, at a comparatively low temperature, and utterly inoperative as a heating body. In other words, the carbonaceous part has *to wait its turn* for that heat which is essential to its own combustion, and in its own peculiar way, as will be explained hereafter.

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* Many instances of inattention might here be given. The following will suffice. In a popular treatise on the steam-engine, by Dr. Lardner, speaking of Brunton's revolving grate, he observes, "The coals are let down from the hopper on the grate, and as they descend in very small quantities at a time, *they are almost immediately ignited.*" Here the *coal* is represented as being *ignited,* or converted into flame, which is incorrect. *Coal-gas* may be converted into flame, and *coke* may be ignited, but *coal* can neither be ignited nor converted into flame.

Again, "But, until their ignition is complete," a *smoke* will arise, which, passing to the flue over the burning coal, *will be ignited.*" Here it is the *gas* which is ignited — the term *smoke* being improperly used instead of *gas.* This, also, is incorrect, as *smoke,* properly speaking, being once formed, cannot be ignited or inflamed in the same furnace.

We also see, that if this bituminous part be not consumed and turned to account, it would have been better had it not existed in the coal; as such heat would, in that case, have been saved and become available for the business of the furnace. To this circumstance may be attributed the alleged comparatively greater heating properties of coke, or anthracite, over bituminous coal.

The point next under consideration will be the processes incident to the combustion of the *gaseous portion* of the coal, as distinct from the *carbonaceous* or *solid* portion.

CHAPTER II.

OF GASEOUS COMBINATIONS, AND PARTICULARLY OF THE UNION OF COAL GAS AND AIR.

HAVING pointed out the leading characteristic in the use of coal, arising out of its elementary divisions, *bituminous* and *carbonaceous,* our next step is, its union with atmospheric air. This part of the subject will require the more attention, as the practicable economy in the use of coal will be found connected with the combustion of the gases. The mechanical engineer may ask, What has this to do with boiler-making and furnace-building? Nevertheless, it involves the whole question of right or wrong, so long as a furnace is to be part of a boiler, and that coal is to be consumed in that furnace.

On the application of heat to bituminous coal, the first result, as already mentioned, is its absorption by the coal, and the disengagement of gas, from which flame is exclusively derivable.

The constituents of this gas are, *hydrogen* and *carbon: and* the unions which alone concern us here are, *carburetted hydrogen,* and *bi-carburetted hydrogen,* commonly called olefiant gas.

Combustibility is not a quality of the combustible, *taken by itself.* It is, in the case now before us, the union of the *combustible* with *oxygen,* and which, for this reason, is called the "*supporter;*" neither of which, however, *when taken alone,* can be consumed.*

---

* "In ordinary language, a body is said to burn when its elements unite with the oxygen of the air, and form new products. One of the bodies, as hydrogen, is termed the burning or combustible body, and the oxygen is said to be the supporter of combustion; but this language, although convenient for common use, is incorrect as a scientific expression, for oxygen may be

To effect combustion, then, we must have a *combustible* and a *supporter* of combustion. Strictly speaking, combustion means *union;* but it means *chemical* union.

Let us bear in mind, that coal gas, whether generated in a retort or a furnace, is essentially the same. Again, that, strictly speaking, it is not inflammable; as, *by itself,* it can neither produce flame nor permit the continuance of flame in other bodies; a lighted taper introduced into a jar of carburetted hydrogen, (coal gas,) so far from inflaming the gas, is itself instantly extinguished. Effective combustion, for practical purposes, is, in truth, a question more as regards *the air* than the *gas.* Besides we have no control over the gas, as to quantity, after having thrown the coal on the furnace, though we *can* exercise a control over that of the air, in all the essentials to perfect combustion. It is this which has done so much for the perfection of the *lamp,* and may be made equally available for the *furnace;* yet, strange to say, in an age, when chemical science is so advanced, and in a matter so purely chemical, this is precisely what is least attended to in *practice.* The *how,* and the *when,* and the *where* this controlling influence over the admission and action of the air is to be exercised, are points demanding the most serious consideration, and can only be decided on *strict chemical principles.*

---

burned in a vessel of hydrogen, as well as hydrogen in a vessel of oxygen, the one and the other being equally active in the process, and being related to each other in every way alike."—*Elements of Chemistry, by Robert Kane, M.D.* Part I., p. 285. 1840.

CHAPTER III.

OF THE CONSTITUENTS OF COAL GAS AND AIR, AND THE RELATIVE QUANTITIES REQUIRED FOR COMBUSTION.

THE first step towards effecting the combustion of any gas, is the ascertaining the quantity of *oxygen* with which it will chemically combine, and the quantity of *air* required for supplying such quantity of *oxygen*. Here, then, we are called on for strict chemical proofs—these several quantities depending on the faculty of each in combining with certain definite proportions of the other—the supporter; these respective proportions being termed "*equivalents*," or combining volumes.

Now, the doctrine of "equivalents," that all-convincing proof of the truths of chemistry, reduces, to a mere matter of calculation, that which would otherwise be a complicated tissue of uncertainties.

Much of the apparent complexity which exists on this head arises from the disproportion between the relative *volumes*, or *bulk*, of the constituent atoms of the several gases, as compared with their respective *weights*. For instance, an atom of *hydrogen* is *double* the bulk of an atom of *carbon vapour;* yet the latter is *six times the weight* of the former.

Again, an atom of hydrogen is double the bulk of an atom of oxygen; yet the latter is *eight* times the weight of the former.

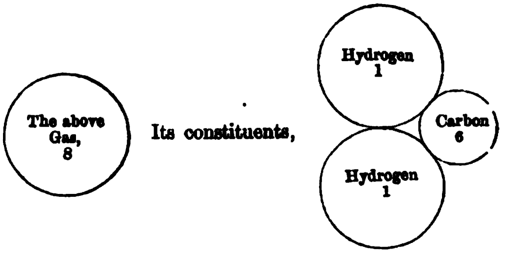
So of the constituents of atmospheric air—nitrogen and oxygen. An atom of the former is double the bulk of an atom of the latter; yet, in weight, it is as fourteen to eight.

I have stated, that there are two descriptions of hydro-carbon gases in the combustion of which we are concerned; both being generated in the furnace, and even at the same time, namely, the *carburetted* and *bi-carburetted* hydrogen gases, the proportion of the latter in coal gas being estimated at about ten per cent. For the sake of simplifying the explanation, I will confine myself to the first.

On analyzing this gas, we find it to consist of two volumes of hydrogen and one of carbon vapour; the gross bulk of these three being *condensed into the bulk of a single atom of hydrogen*, that is, into two-fifths of their previous bulk, as shewn in the annexed figures. Let figure 1 represent an atom of coal gas—carburetted hydrogen—with its constituents, carbon and hydrogen; the space enclosed by the lines representing the relative size or volume of each; and the numbers representing their respective weights—hydrogen being taken *as unity* both for volume and weight.*

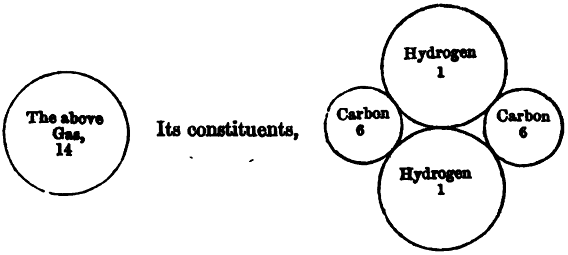
Carburetted Hydrogen.

Fig. 1.



Bi-carburetted Hydrogen.

Fig. 2.



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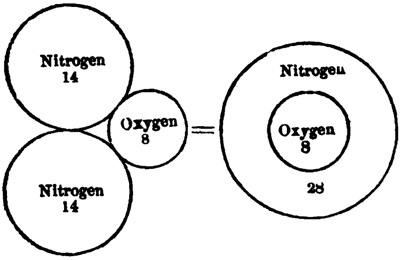
* "Ce gaz (carburetted hydrogen) est composé de 75.17 parties (by weight) de carbone, et 24·33 d'hydrogène; ou, d'un *volume* de carbone gazeux et quatre volumes de gaz hydrogène, condensés à la moitié du volume de ce dernier, ou, aux 2/5 du volume total du gaz, de manière que de cinq volumes simples, il n'en résulte pas plus de deux de la combinaison."—*Berzelius* Vol. I., 330.

Let us now, in the same analytical manner, examine an atom of atmospheric air, the other ingredient in combustion.

Atmospheric air is composed of two atoms of nitrogen and one atom of oxygen; each of the former being *double* the volume of an atom of the latter, while their relative weights are as fourteen to eight: the gross *volume* of the nitrogen, in air, being thus four times that of the oxygen; and in *weight*, as twenty-eight to eight, as shewn in the annexed figure 3.

Atmospheric Air.

Fig. 3.



In the coal gas we found the constituents condensed into *two-fifths* of their gross bulk: this is not the case with *air;* an atom of which is the same, *both as to bulk and weight,* as the sum of its constituents, as here shewn. Thus, we find, the oxygen bears a proportion in volume to that of the nitrogen, as one to five; there being but 20 per cent. of oxygen in atmospheric air, and 80 per cent. of nitrogen.

We now proceed to the ascertaining the *separate quantity of oxygen required by each of the constituents* (of the gas), so as to effect its perfect combustion.

With respect to this reciprocal saturation, the great natural law is, that *bodies combine in certain fixed proportions only,* both in *volume* and *weight.*[*]

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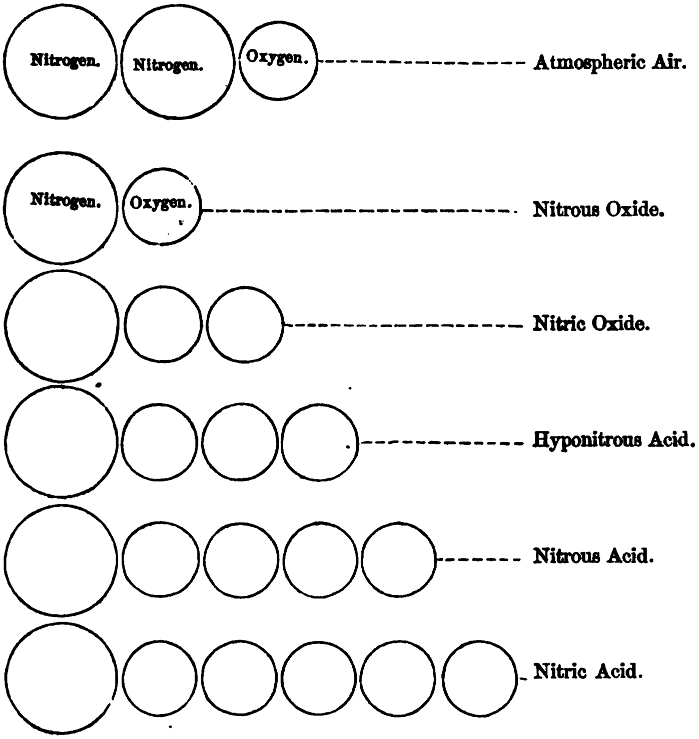
[*] "L'expérience a démontré que, de même que les élémens se combinent dans des proportions fixes et multiples, relativement à leur *poids,* ils se combinent aussi, d'une manière analogue, relativement à leur *volume,* lorsqu'ils sont à l'état de gaz: en sorte qu'un volume d'un élément se combine, ou, avec un volume égal au sien, ou avec 2, 3, 4 et plus de fois son volume d'un autre élément à l'état de gaz. En comparant ensemble les phénomènes connus des combinaisons de substances gazeuses, nous découvrons les *mêmes lois* des pro-

The important bearings of this elementary principle cannot be more strikingly illustrated than in the combinations of which the elements of atmospheric air are susceptible.

For instance, oxygen unites chemically with nitrogen in five different proportions, forming five distinct bodies, each essentially different from the others, thus:

Atoms.	*Weight.*	*Atoms.*	*Weight.*		*Gross Weight.*
1 of Nitrogen	14 unites with	1 of Oxygen	8 forming	Nitrous Oxide	22
1	14	2	16	Nitric Oxide	30
1	14	3	24	Hyponitrous Acid	38
1	14	4	32	Nitrous Acid	46
1	14	5	40	Nitric Acid	54

Or thus: Fig. 4.

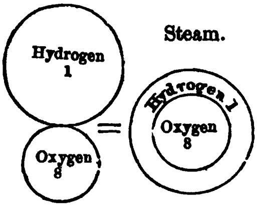


portions fixes, que celles que vous venons de déduire de leurs proportions *en poids:* ce qui donne lieu à une manière de se représenter les corps, qui doivent se combiner, sous des *volumes* relatifs à l'état de gaz. Les degrès de combinaisons sont absolument les mêmes, et ce qui dans l'une est nommé *atome,* est dans l'autre appelé *volume."—Berzelius,* Vol. IV., 549.

We here find the elements of the air we breathe, by a mere change in the *proportions* in which they are united, forming so many distinct substances, from the *laughing gas*, (nitrous oxide,) up to that most destructive agent, *nitric acid*, commonly called *aqua-fortis*.

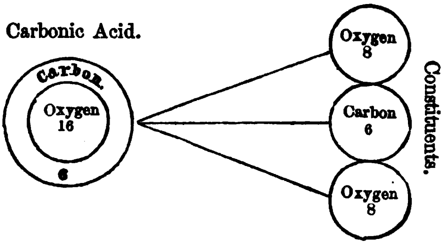
On the application of heat, or what may be termed the firing or lighting the gas, when duly mixed with air, the hydrogen *separates itself from its fellow-constituent, the carbon*, and forms an union with oxygen, the produce of which is water. The saturating equivalent of an atom, or any other given quantity of hydrogen, is not *double* the volume, as in the case of the carbon, but *one-half* its volume only—the product being aqueous vapour, that is, *steam;* the relative weights of the combining volumes being 1 of hydrogen to 8 of oxygen; and the bulk, when combined, being two-thirds of the bulk of both taken together, as shewn in the annexed figure.

Fig. 5.



Again, the carbon, on meeting its equivalent of oxygen, unites with it, forming carbonic acid gas, composed of *one atom* of carbon, (by weight 6,) and *two atoms* of oxygen, (by weight 16,) the latter, in volume, being double that of the former, as in the annexed figure.

Fig. 6.



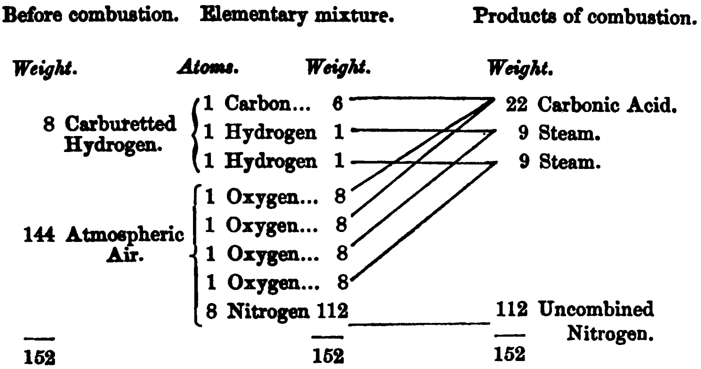
No facts in chemistry, therefore, can be more decidedly proved, than that one atom of hydrogen and one atom of oxygen (*the former being double the bulk of the latter*) unite in the formation of water; and, further, that one atom of carbon vapour and two atoms of oxygen (*the latter being double the bulk of the former*) unite in the formation of carbonic acid gas.

Having thus ascertained the quantity of *oxygen* required for the saturation and combustion of the two constituents of coal gas, the remaining point to be decided is, *the quantity of air that will be required to supply this quantity of oxygen.*

This is easily ascertained, seeing that we know precisely the proportion which oxygen bears, in volume, to that of the air. For, as the oxygen is but *one-fifth* of the bulk of the air, *five* volumes of the latter will necessarily be required to produce *one* of the former; and, as we want *two* volumes of oxygen for each volume of the coal gas, it follows, that, *to obtain those two volumes, we must provide ten volumes of air.*

As the proportion of air required for the combustion of the *bi-carburetted hydrogen* (olefiant gas) is necessarily larger than for the *carburetted* hydrogen, a diagram of each is annexed, shewing the volume of air required for combustion.

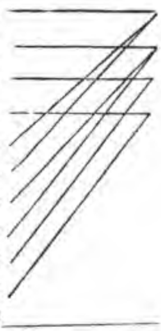
Carburetted Hydrogen.



Before combustion.		Elementary mixture.		Products of combustion.	
Weight.		*Atoms.*	*Weight.*	*Weight.*	
8	Carburetted Hydrogen.	1 Carbon...	6	22	Carbonic Acid.
		1 Hydrogen	1	9	Steam.
		1 Hydrogen	1	9	Steam.
144	Atmospheric Air.	1 Oxygen...	8		
		1 Oxygen...	8		
		1 Oxygen...	8		
		1 Oxygen...	8		
		8 Nitrogen	112	112	Uncombined Nitrogen.
152			152	152	

Bi-Carburetted Hydrogen.

Before combustion.		**Elementary mixture.**		**Products of combustion.**	
Weight.		*Atoms.*	*Weight.*	*Weight.*	
		1 Carbon...	6	22	Carbonic Acid.
14	Bi-carburetted Hydrogen.	1 Carbon...	6	22	Carbonic Acid.
		1 Hydrogen	1	9	Steam.
		1 Hydrogen	1	9	Steam.
		1 Oxygen...	8		
		1 Oxygen...	8		
		1 Oxygen...	8		
216	Atmospheric Air.	1 Oxygen...	8		
		1 Oxygen...	8		
		1 Oxygen...	8		
		12 Nitrogen	168	168	Uncombined Nitrogen.
230			230	230	



CHAPTER IV.

OF THE QUANTITY OF AIR REQUIRED FOR THE COMBUSTION OF CARBON, AFTER THE GAS HAS BEEN GENERATED.

Having disposed of the question of quantity, as regards the supply of air required for the saturation and combustion of the *gaseous* portion of coal, we have now to answer a corresponding question, with reference to the *carbonaceous* part resting in a solid form on the bars *after* the gaseous matter has been evolved.

Carbon is stated, by chemists, to be susceptible of uniting with oxygen in three proportions, by which three distinct bodies are formed, possessing distinct chemical properties.

This peculiarity of the unions of carbon with oxygen is wholly unattended to in practice: yet we shall see how essential it is in considering the quantity of air to be introduced to a furnace.

These three proportions, in which carbon unites with oxygen, form, first, *carbonic acid;* second, *carbonic oxide;* and, third, *carbonous acid* (or oxalic acid). With the first and second only we have to deal in the *furnace*—the difference between these two formations being peculiarly important to our present subject.

Were carbonic acid the only product of the combustion of the carbon of the coal in the furnace, no more would here have to be said; but there is the other state in which we find carbon uniting and passing away with oxygen, and which gives rise to considerations of the utmost importance in this branch of the inquiry. This other state is that of carbonic *oxide,* the formation of which, in the furnace, is wholly unheeded in practice, although its influence on the quantity of heat obtained is very considerable, the very name of this gas not having hitherto been noticed by any writer in connexion with combustion in the furnace.

Carbonic *acid*, we have seen, is a compound of one atom of carbon with two atoms of oxygen; while carbonic *oxide* is composed of the same quantity of carbon with but *half* the above quantity of oxygen, as in the annexed figures.

Fig. 7.

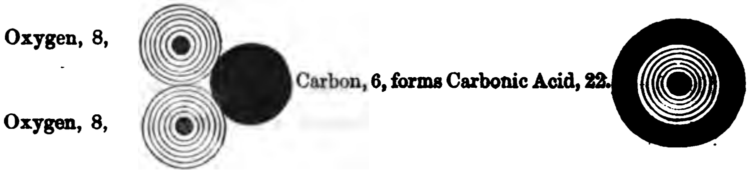
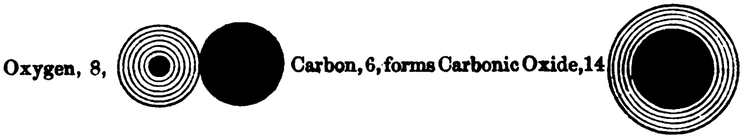


Fig. 8.



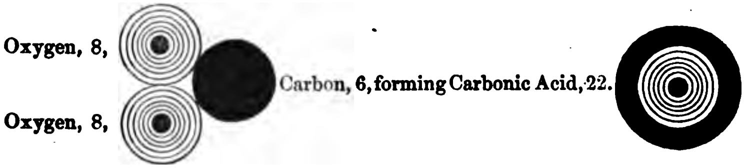
Here we see, that carbonic *oxide*, though containing but one-half the quantity of oxygen, is yet of the same bulk or volume as carbonic *acid*, a circumstance of considerable importance on the mere question of *draught*, and supply of air, as will be hereafter shewn.

Now, the combustion of this *oxide, by its conversion into the acid*, is as distinct an operation as the combustion of the carburetted hydrogen, or any other combustible; yet all this is wholly overlooked in *practice* in the operations carried on in the furnace.

But the most important view of the question, and one which is little known to practitioners outside the laboratory, is as regards the *formation* of this *oxide;* and this is the part of the inquiry which most requires our attention.

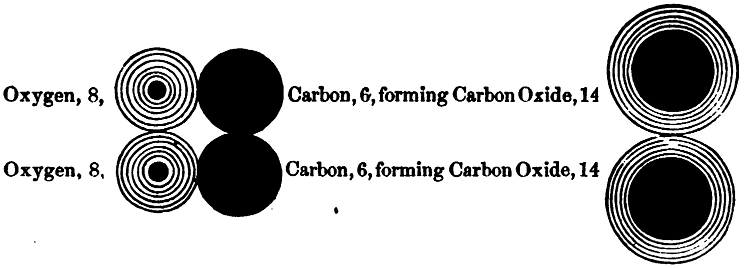
The *direct* effect of the union of carbon and oxygen is the formation of carbonic *acid*. If, however, we *abstract* one of its portions of *oxygen*, the remaining proportions would then be those of carbonic *oxide*. It is equally clear, however, that if we *add* a second portion of *carbon* to carbonic *acid*, we shall arrive at the same result, namely, the having carbon and oxygen combined in equal proportions, as we see in carbonic *oxide*.

Fig. 9.



By the addition, then, of a *second* proportion of carbon to the above, *two* volumes of carbonic *oxide* will be formed—thus:

Fig. 10.


Oxygen, 8,
Carbon, 6, forming Carbon Oxide, 14
Oxygen, 8,
Carbon, 6, forming Carbon Oxide, 14

Now, if these two volumes of carbonic oxide cannot find the oxygen required to complete their *saturating* equivalents, they pass away necessarily but *half consumed*, a circumstance which is constantly taking place in all furnaces where the air has to pass through a body of incandescent carbonaceous matter.

This frequently leads to a fatal error in what is called the "combustion of smoke": for if the carbonaceous constituent of coal, and, while yet at a high temperature, encounters carbonic *acid*, this latter, taking up an additional portion of carbon, is converted into carbonic *oxide*, and again becomes a gaseous and invisible combustible.

The most prevailing operation of the furnace, however, and by which the largest quantity of carbon is lost in the shape of carbonic *oxide*, is thus:—The air, on entering from the ashpit, gives out its oxygen to the glowing carbon on the bars, and generates much heat in the formation of carbonic acid. This *acid*, necessarily at a very high temperature, passing upwards through the body of incandescent solid matter, takes up an additional portion of the carbon, and becomes carbonic *oxide*.*

Thus, by the conversion of one volume of *acid* into two volumes of *oxide*, heat is actually absorbed, while we also lose the portion of carbon taken up during such conversion, and are deceived by imagining we have "*burned the smoke*."

The formation of this compound, carbonic oxide, being thus attended by circumstances of a curious and involved nature, is, probably, the cause of the prevailing ignorance of its properties. For, while we find, in every mouth, the term *carbonic acid*, as the product of combustion, we hear nothing of *carbonic oxide*, one of the most waste-inducing compounds of the furnace, unless provided with its equivalent volume of air, by which its combustion will be effected.†

Another important peculiarity of this gas (carbonic oxide) is, that, by reason of its already possessing *one-half* its equivalent of oxygen, it inflames at a lower temperature than the ordinary *coal-gas*; the consequence of which is, that the *latter*, on passing into the flues, is often cooled down below the tem-

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[*] "Carbonic oxide may be obtained by transmitting carbonic acid over red hot fragments of charcoal contained in an iron or porcelain tube. It is easily kindled: combines with half its volume of oxygen, forming carbonic acid, which retains the original volume of the carbonic oxide. The combustion is often witnessed in a coke or charcoal fire. The carbonic acid produced in the lower part of the fire is converted into carbonic oxide as it passes up through the red hot embers."—*Graham's Elements of Chemistry.*

[†] "Among the stove-doctors of the present day, none are more dangerous than those who, on the pretence of economy and convenience, recommend to keep a large body of coke burning slowly, with a slow circulation of air. An acquaintance with chemical science would teach them, that, in the obscure combustion of coke or charcoal, much carbonic oxide is generated, and much fuel consumed, with the production of little heat; and physical science would teach them, that, when the chimney draught is languid, the burned air is apt to regurgitate through every seam or crevice, with the imminent risk of causing asphyxia, or death, to the inmates of apartments so preposterously heated."—*Dr. Ure's Paper on Ventilating and Heating Apartments, read before the Royal Society, 16th June,* 1836.

perature of ignition; while the *former* is sufficiently heated, even after having reached the top of the chimney, and is there ignited on meeting the air. This is the cause of the red flame often seen at the tops of chimneys and the funnels of steam-vessels

We may thus set it down as a certainty, that, if the carbon, either of the gas or of the solid mass on the bars, passes away in union with oxygen in any other form or proportion than that of *carbonic acid*, a commensurate loss of heating effect is the result.

Hence we see how the peculiar influence which carbonic *oxide* exercises, in its formation and combustion, justifies the observation of Chevreul, in his "Leçons de Chimie," that "*la connaissance de ses propriétés est indispensable pour bien connoître le carbon.*"

Of the application of carbonic oxide in the manufacture of iron, and the mode of effecting its combustion, notice will be taken in a subsequent chapter.

CHAPTER V.

OF THE QUALITY OF THE AIR ADMITTED TO A FURNACE.

WHEN we speak of mixing a given quantity of oxygen with a given quantity of coal gas, we do so because we know that the former is required to saturate the latter; so when we speak of mixing a given volume of atmospheric air with a given volume of coal-gas, we do so knowing that such precise quantity of *air* will provide the required quantity of *oxygen.*

If, however, by any circumstance, accidental or otherwise, the air we employ has either lost any portion of its oxygen, or is mixed with any other gas or matter, it no longer bears the character of pure atmospheric air, and cannot satisfy the condition as to *quantity* of *oxygen* which was essential to our purpose.

We require *ten* cubic feet of *air* to supply *two* cubit feet of *oxygen* to effect the combustion of *one* cubic foot of coal gas; but if this quantity of air does not contain this 20 per cent., it is manifest we cannot obtain it. The air, in this case, may be said to be vitiated or deteriorated; and, in this sense, the *quality* of the air we employ is entitled to serious consideration.

Let us now inquire how far the ordinary mode of constructing and managing our furnaces enables us to satisfy this condition, namely, the providing *unvitiated air* both to the solid *carbonaceous* portion of the coal on the bars, and the *gaseous* portion in the furnace.

Tredgold, and others after him, overlooking these distinctive features in the processes which *coal* undergoes in its progress towards combustion, give preposterous directions as to the introduction of air. He says, "The opening to admit air (the ashpit) should be sufficiently large for producing the greatest quantity of steam that can be required, but not larger." Here we find the "*quantity of steam*" actually considered as dependent on the area of "the *opening to admit air*" to the ashpit, than which nothing can be more incorrect.* If, then, Tredgold could so palpably overlook the *chemical* essentials in the combustion of the two separate constituents of coal, it cannot be a matter of surprise that those who have been taught to follow in his steps should have made so little advance in perfecting our system of furnaces.

I have alluded to Tredgold's directions with the view of pointing attention to that which has hitherto been so neglected, namely, the two distinct operations of supplying air to the *gas* generated in the upper part of the furnace, and to the solid *carbon* resting on the bars; and, also, to the injury caused by compelling the *whole supply* to pass through the ashpit, and through such solid carbon; by which not only a deficiency of oxygen is occasioned in the air intended for burning the gas, but an undue and injurious urging of the combustion of the carbonaceous matter.†

Yet this is our daily practice. We bring air to the gases which has already been employed in a separate and even destructive process, and yet expect the result to be satisfactory and the combustion complete. And when we find, instead of producing carbonic acid and water, that we have produced a large volume of *smoke*—of unconsumed combustible matter—we then set about inventing processes by which *this smoke is to be "consumed,"* and the evil we had ourselves produced, corrected.

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* "In the construction of fire-places for boilers," he observes, "we have to combine every thing which is likely to add to the effect of fuel, and to avoid every thing which tends to diminish it, as far as possible. Now, without some knowledge of the nature of the operation of burning, it will scarcely be possible to do any thing good *except by mere accident.* We should be like seamen in a vessel at sea without a compass, with as little chance of steering to the intended port."

No man can question whether the absence of a compass would not be preferable to one which should directly induce us to steer a wrong course.

† "To succeed in consuming the combustible gases," observes Tredgold, "it is necessary that they mix with air that has become hot, by passing *through, over, or among the fuel which has ceased to smoke;* the words of the patent of Mr. Watt, dated 1785."

Here there can be no mistake, yet nothing can be more unscientific or unsound in principle. The inevitable result of this operation would be: first, the depriving the air, more or less, of its oxygen; and, second, by urging this increased quantity of air to act like a blast on such red hot fuel, to consume it with unnecessary and injurious rapidity.

CHAPTER VI.

OF THE MIXING AND INCORPORATION OF AIR AND COAL GAS.

HAVING disposed of the questions regarding the *quantity* and *quality* of the air to be admitted, our next consideration is, the effecting such a mixture as is required for effective combustion.

It seems taken for granted, in practice on the large scale, that, if air, by *any means*, be introduced to " the fuel in the furnace," it will, as a matter of course, mix with the gas, or other combustible, in a proper manner, and assume the state suitable for combustion, whatever be the nature or state of such fuel. Yet, as well might it be said, that bringing together given quantities of nitre, sulphur, and charcoal, in *masses*, was sufficient for the constitution of gunpowder. It is, however, the proper distribution, mixture, and incorporation of the respective elementary atoms of those masses which impart efficiency and simultaneousness of action, and, necessarily, their explosive character:* and so, also, in the bringing bodies of gas and air into a state of preparation for efficient and simultaneous combustion.

In operating in the laboratory, when we mix a measured jar of an inflammable gas with a due complement of oxygen gas, the operation being performed leisurely, due incorporation follows, and no question as to the *want of time* arises.

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* Doctor Ure in his *Chemical Dictionary*, puts this clearly and forcibly. Gunpowder is composed of given weights of nitre, charcoal, and sulphur, "*intimately blended* together by long pounding in wooden mortars." Again, " The variations of strength, in different samples, are generally occasioned by the more or less *intimate division and mixture* of the parts. The reason of this may be easily deduced from the consideration, that nitre does not detonate until in contact with inflammable matter: whence the whole detonation will be more speedy the *more numerous the surfaces of contact*."

In this operation the quantities are small: both bodies are gaseous: there is no disturbing influence from the presence of other matter: the relative quantities of both are in saturating proportions; and above all, are unaffected by current or draught.

But compare this deliberate laboratory operation with what takes place in the furnace. First, the quantities are large: secondly, the bodies to be consumed are partly gaseous, partly solid: thirdly, the gases evolved from the coal are part combustible and part incombustible: fourthly, they are forced into connection with a large and often overwhelming quantity of the products of combustion, chiefly carbonic acid: fifthly, the very air introduced is itself deteriorated in passing through the bars and incandescent fuel on them, and thus deprived of much of its oxygen: sixthly, and above all, instead of being allowed a suitable time, the whole are hurried away by the current or draught in large masses.

Dr. Reid, in his "Elements of Chemistry," when describing the detonating mixture, directs "that the oxygen be *well mingled* with the hydrogen." Here deliberate measures are taken for the diffusion of a mere phialful, yet we take no pains to have these same ingredients "*well mingled*" in the furnace!

In the "Experimental Researches on the Diffusion of Gases," by Mr. Graham, we have abundant proof of the absolute necessity for giving time. In one case, he observes, "the receiver was filled with 75 volumes of hydrogen, and 75 of olefiant gas, agitated and allowed to stand over water for *twenty-four hours, that the mixture might be as perfect as possible.*" In general, he allowed four hours to elapse before he considered the gases adequately mixed.

Professor Daniell finds, that even in laboratory experiments, it is essential to give an excess of oxygen to secure an adequate portion reaching each atom of the gas to be consumed, no more, however, being consumed than its due equivalent of oxygen.*

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* "In the process which has been described for collecting the products of the detonation of hydrogen, and oxygen it is necessary *that they be mixed*

But the observations of Professor Faraday should satisfy us at once on the question of *time*, and justifies the attributing so much importance to this hitherto neglected feature in the process of combustion on the large scale. In his "Chemical Manipulations," p. 360, he says, "It will be proper to observe, that, although in making mixtures of gases, they will become uniform without agitation, *if sufficient time be allowed*, the period required will be *very long*, extending even to hours, in narrow vessels. If hydrogen be thrown up into a *wide* jar full of oxygen, so as to fill it, and no further agitation given, the mixture, *after the lapse of several minutes*, will still be of different composition above and below." Here are *several minutes* proved to be necessary in effecting adequate mixture in a jar full of the gases, whereas we cannot afford even *several seconds* for the mixing of a furnace full.

Now this brings us to the conclusion, that, as we cannot *force* the gas and air to mingle with sufficient rapidity, under the ordinary circumstances of the furnace, our views should be directed to the effecting such modifications of that furnace as will aid nature in those arrangements which are essential to combustion, rather than in obstructing them.

Having consulted Professor Daniell on this subject, his opinion, here given, is of importance.

OPINION.

"King's College, 8th August, 1840.

"There can be no doubt, that the affinity of hydrogen for oxygen under most circumstances is stronger than that of carbon. If a mixture of two parts of hydrogen and one of carbonic *acid* be passed through a red-hot tube, water is formed, a portion of charcoal is thrown down, and carbonic *oxide* passes over with the excess of hydrogen.

very accurately, in the proportion of two of hydrogen to one of oxygen. In these proportions they enter into combination, and in none other; and if either were in excess, the surplus would be left after detonation."—*Daniell's Introduction to Chemical Philosophy.*"

"With regard to the different forms of hydro-carbon, it is well known, that the whole of the carbon is never combined with oxygen in the processes of detonation or silent combustion, *unless a large excess of oxygen be present.*

"For the complete combustion of olefiant gas, it is necessary to mix the gas with *five* times its volume of oxygen, *though three only are consumed.* If less be used, part of the carbon *escapes combination,* and is deposited as a black powder. Even sub-carburetted hydrogen it is necessary to mix with more than twice its bulk of oxygen, or the same precipitation will occur.

"It is clear, therefore, that the whole of the hydrogen of any of these compounds of carbon may be combined with oxygen, while a part of their carbon may escape combustion, and *that* even when enough of oxygen is present for its saturation.

"That which takes place when the mixture is designedly made in the most perfect manner must, undoubtedly, arise in the common processes of combustion, where the mixture is fortuitous and much less intimate. Any method of ensuring the complete combustion of fuel, consisting partly of the volatile hydro-carbons, *must be founded upon the principle of producing an intimate mixture with them of atmospheric air, in excess,* in that part of the furnace to which they naturally rise. In the common construction of furnaces this is scarcely possible, as *the oxygen of the air, which passes through the fire bars,* is mostly *expended upon the solid part of the ignited fuel with which it first comes in contact.*

"J. F. DANIELL.

"To C. W. Williams, Esq., &c. &c."

CHAPTER VII.

OF THE CONDITIONS ON WHICH THE INCORPORATION OF THE GAS AND AIR ARE EFFECTED PREPARATORY TO COMBUSTION.

Professor Daniell, in the opinion just quoted, states the true principle on which any improvement in our furnaces for ensuring the complete combustion of bituminous coal must be founded, namely, the producing an intimate previous mixture between the gaseous portion and atmospheric air.

On this head we find many convincing illustrations of what nature requires, and what a judicious mode of bringing air to the gas can effect, in the common candle, and in the Argand lamp, that I propose examining these two exemplifications of gaseous combinations and combustion, in the manner adopted by the best British and continental chemists.

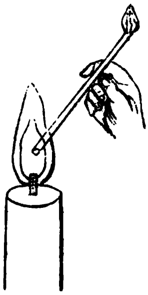
Mr. Brande observes, "In a common candle, the tallow is drawn into the wick by capillary attraction, and there converted into vapour, which ascends in the form of a conical column, and has its temperature sufficiently elevated to cause it to combine with the oxygen of the surrounding atmosphere, with a temperature equivalent to a *white heat.* But this combustion is *superficial only,* the flame being a thin film of white hot vapour, enclosing an interior portion, *which cannot burn for want of oxygen.* It is in consequence of this structure of the flame that we so materially *increase its heat,* by propelling a current of air through it by the *blow-pipe.*"

Dr. Reid observes, "The flame of a candle is produced by the gas formed around the wick acting upon the oxygen of the air: *the flame is solely at the exterior* portion of the ascending gas.

All *without* is merely heated air, or the products of combustion; all *within* is *unconsumed gas, rising in its turn* to affect (mingle with) the oxygen of the air.

"If a glass tube be introduced within the flame of a lamp or candle, (as represented in Fig. 11,) part of the unconsumed gas passes through it, and may be kindled as it escapes."

Fig. 11.



Berthier, vol. i., p. 177, observes, "The flame presents four distinct parts: namely, first, the *base*, of a sombre blue: this is the gas which burns with difficulty, because it has not yet acquired a sufficiently high temperature; secondly, an *interior dark cone:* this is combustible gas *highly heated, but which does not burn, because it is not mixed with air;* thirdly, the *brilliant conical envelope:* in this part, combustion takes place with a deposit of carbon; fourthly, a *conical envelope,* which gives but little light, ('*très peu lumineuse,*') surrounding the whole flame, extremely thin or attenuated ('*extrêmement mince*'). Combustion is complete in this part, and it is at its contact with the *luminous* envelope that the temperature is the highest."

Berzelius, vol. viii., p. 151, observes of the flame of a candle: —At its base we perceive a small part of a deep blue colour. In the middle is a dark part which contains the gas evolved from the wick, but which, *not being yet in contact with the air, cannot burn:* outside of this is the brilliant part of the flame. We also perceive on the confines of this latter, a thin faintly luminous envelope, which becomes larger towards the summit of the flame. It is there that the flame is hottest. Dr. Thomson, in his work on "Heat and Electricity," and Dumas, in his

"Traité de Chimie appliquée aux Arts," give similar illustrations of the combustion of the gas in the flame of a candle. Dr. Ure observes, "Nothing places in a clearer light the heedlessness of mankind to the most instructive lessons than their neglecting to perceive the difficulty of duly intermingling air with inflammable vapours, for the purpose of their combustion, as exhibited in the everyday occurrence of the flame of a tallow candle, or common oil lamp; for, though this flame be in contact, externally, with a current of air created by itself, yet a large portion of the tallow and oil passes off unconsumed, with a great loss of the light and heat which they are capable of producing."

It is here to be remarked, that notwithstanding the attention given to the subject by these chemical authorities, they have, nevertheless, omitted noticing the presence of the *water* produced by the combustion of the gas, and which will, hereafter, be shewn to be one of the most important products escaping from the furnace. This will be treated in a separate chapter.

All these authorities agree in the main facts: *first,* that the dark specks in the centre of the flame is a body of unconsumed gas *ready for combustion,* and only waiting the *preparatory* step — the *mixing* — the *getting into contact* with the oxygen of the air: *secondly,* that that portion of the gas in which the due mixing has been effected, forms but a thin film on the *outside* of such unconsumed gas: *thirdly,* that the products of combustion form the transparent envelope, which may be perceived on close inspection: *fourthly,* that the collection of gas in the *interior* of the flame cannot burn *there* for want of oxygen.

Now these points involve the whole of the case of the *furnace*: — they reveal the difference between perfect and imperfect combustion. The bodies of gas and air have, it is true, *free access* to each other: yet, *time is wanting* for their due mixture. Thus, diffusion and combustion only proceed, *pari passu,* as the constituent atoms of the gas, "*taking their turn,*" are enabled to get into contact with their respective equivalent atoms of atmospheric oxygen.

I have not hitherto quoted Sir Humphry Davy on this head, for his whole "Researches on Flame" go in corroboration of the facts here stated, and the inferences drawn by so many competent authorities.*

If, then, the unrestricted access of air to this small flame is not able, by the laws of diffusion, to form a due mixture in time for ignition, *à fortiori*, it cannot do so when the supply of air is *restricted* and that of the gas *increased*.

Dr. Reid, speaking of the Argand lamp, Fig. 12, observes, that the intensity of the heat is augmented by causing the air to enter in the middle of a circular wick, or *series of gas-jets*, so that more gas is consumed *within a given space* than in the ordinary manner.

But why is more gas consumed *within this given space?* Solely because more capability for mixture is afforded, and a greater number of accessible points of *contact* obtained, arising out of this series of jets. This may be seen in Fig. 13, where the inner surfaces, *a a*, are shewn in addition to the outer ones *b b*.

Fig. 12.

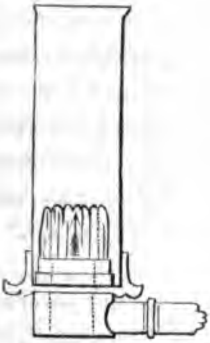


Fig 13.

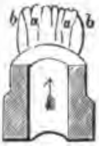
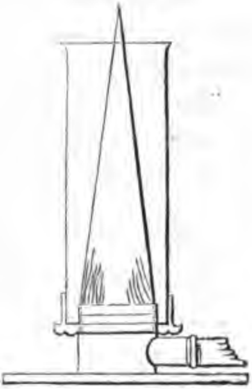


Fig. 14.



"If the aperture," he observes, "by which air is admitted into the interior of the flame be closed, the flame immediately assumes the form shewn in Fig. 14; part of the supply of air being thus cut off, it extends farther into the air before it meets with the oxygen necessary for its combustion."

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* "In looking steadfastly at flame," he observes, "the part where the combustible is volatilized is seen, and it appears darker, contrasted with the part in which it *begins* to burn, that is, where it is *so mixed with air* as to become explosive."

Here we trace the *length* of the flame to the diminished rate of mixing and combustion, occasioned by the want of adequate access, within any given time, between the gas and the air, *until too late*—until the ascending current has carried them beyond the temperature required for chemical action; the carbonaceous constituent then losing its gaseous character, assuming its former colour and state of a black pulverulent body, and becoming true smoke.

In looking for a remedy for the evils arising out of the hurried state of things which the interior of a furnace naturally presents, and observing the means by which the gas is effectually consumed in the Argand lamp, it seemed manifest, that, if the gas in the furnace could be presented, by means of *jets*, to an adequate quantity of air, as it is in the lamp, the result would be the same. The difficulty of effecting a similar distribution of the gas in the furnace, by means of jets, however, seemed insurmountable: one alternative alone remained, namely, that, since the gas could not be introduced by jets into the body of air, *the air might be introduced by jets into the body of gas.*

This, then, is the means which I adopt, and by which I effect a complete combustion of the gases in the furnace, as we do in the lamp. Professor Brande has so clearly described the operation of the jet that I avail myself of his remarks in elucidation of the result produced by a jet of air into a body of gas, and the analogy it bears to that of a jet of gas into a body of air.*

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* "Each jet of air which you admit becomes, as it were, the source or centre of a separate flame, and the effect is exactly that of so many jets of inflammable or coal-gas ignited in the air; only, in your furnace, you invert this ordinary state of things, and use a jet of air thrown into an atmosphere of inflammable gas, thus making an experiment upon a large and practical, which I have often made on a small and theoretical, scale, in illustration of the inaccuracy of the common terms of '*combustible*' and '*supporter of combustion*,' as ordinarily applied.

"I fill a bladder with coal-gas, and attach to it a jet, by which I burn a flame of that gas in an atmosphere of, or a bell glass filled with, oxygen; of course, the gas burns brilliantly, and we call the gas the combustible, and the oxygen the supporter of combustion. If I now invert this common order of things, and fill the bladder with oxygen and the bell glass with coal-gas, I find, that the jet of *oxygen* may be inflamed in the atmosphere of *coal-gas*

This process meets the entire difficulties of the case as to time, current, temperature, and quantity. By this means the process of diffusion is hastened without the injurious effect of cooling: and which always takes place when the air is introduced by large orifices.

The difference, then, between the application of air by means of *the jet*, and that of the ordinary action of the atmosphere, consists in the increased surface it presents for mutual contact in any given unit of time. Let Fig. 15 represent the section of a candle and Fig. 16 that of a diffusion jet. In the former, the gas in the centre meets the air on the exterior. In the latter, the air in the centre issuing into the atmosphere of gas, enlarges its own area for contact mechanically, and consequently, its increased measure of combustion.

Fig. 15.

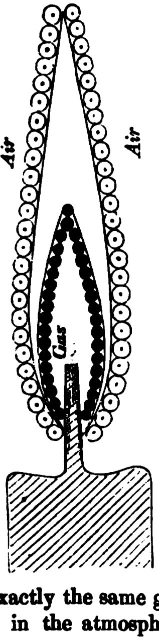
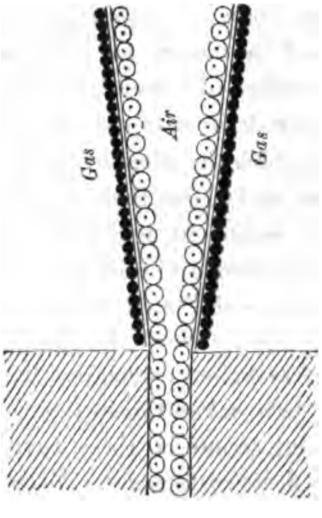


Fig. 16.



with exactly the same general phenomena as when the jet of *coal-gas* is inflamed in the atmosphere of *oxygen*. This is precisely your process. You admit a number of jets of air into a heated, inflammable atmosphere, and so attain its combustion in such a way as to produce a great increase of heat, and, as a necessary consequence, destroy the smoke. You, in fact, convert what is commonly called smoke into fuel, at the *time when* and *place where* this combustion can be most effectively brought about."—*Professor Brande's Letter to the Author*.

Thus we see, that the value of the *jet* arises from the circum stance of its creating, *for itself*, a larger surface for contact, by which a greater number of elementary atoms of the combustible and the supporter, gain access to each other in any given time.

Turn the matter, then, as we may, the question of perfect or imperfect combustion, as far as human means are to be applied, is one regarding the *air*, rather than the *combustible*—the *mode* in which it may be introduced, rather than the *quantities* supplied—the contact of *atoms* rather than of *masses*.

Before concluding this notice on the *mode* of effecting the combustion of the inflammable gases, it will be right to say a few words on some of those recommended by others; namely, such as are founded on the erroneous idea, which appears to have laid hold of the minds of so many inventors of late years, that the gases are *consumable* by being brought into contact with a body of "*glowing incandescent fuel.*" This will be inquired into more in detail when we come to examine the various plans of "smoke-burning" furnaces and boilers. I am here only desirous of checking that misapplication of talent and means which the adoption of this fundamental chemical error induces, and giving them a more correct and useful direction.

This erroneous notion of the supposed combustion of the gases, (or smoke,) by bringing them into contact with a mass of "glowing coals," appears to have originated with Watt; and, having been adopted by Tredgold and others, has since passed into a recognised principle. It appears strange, that, while so many have taken this as their text, or adopted it as their starting-point, none of these inventors have examined, or even doubted, its correctness. Yet any chemical work of authority would have informed them of the well-established fact, that decomposition, not combustion, is the result of a high temperature applied to the hydro-carbon gases—that no possible degree of heat can consume carbon—and that its combustion is merely produced by, and is, in fact, its *union* with, oxygen, which latter, however, they take little care to provide.

It is the palpable oversight of this distinction that has led to that manifest chemical blunder,—the supposing that the coal-gas in a furnace is to be *burned* by the act of bringing it into contact with bodies at a high temperature; or, in the words of the patentees, by "causing it to pass *through*, *over*, or *among* a body of hot, glowing coals." Indeed, these words of Watt, "through, over, or among," have led more men astray, and have occasioned more waste of money, loss of time, and misapplication of talent than almost any other false light of the day.

But, I have said, this erroneous view of the combustion of the gases began with Watt. His patent of 1785 fully justifies this assertion.* In his specification, after reiterating the injunction, that "the smoke or flame is to pass over or through the coked or charred part of the fuel," he sums up in these words: "Lastly, my invention consists in the method of *consuming the smoke and increasing the heat by causing the smoke and flame of fresh fuel to pass through very hot funnels or pipes, or among, through, or near fuel which is intensely hot, and which has ceased to smoke;*" and then follows that part of his instructions which his successors have so strangely neglected, "and by *mixing it with fresh air*, when in these circumstances."

It is clear, Watt had a right conception of the necessity for mixing air with the gas. His error lay in the extent to which he considered the application of heat essential to its combustion. His followers and commentators have neglected that part of his instructions in which he was right—the "mixing with fresh air;" and have fixed their minds on that in which he was wrong—the bringing the gas or smoke "*through*, *over*, or *among* intensely hot fuel." So much, indeed, was Watt impressed with the importance of intense heat, that he actually provides both for the "*fresh air*" and *the gas* passing through the hot fuel on the bars; overlooking the facts, that, in that event, the air would no longer remain *pure;* and that no heat to which he could introduce the air or smoke could equal that created in the furnace by the very act of union between the air and the gas; but which he erroneously imagines can be aided by the heat of the "charred part of the fuel."

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* Watt's patent, of 1785, (see Repertory of Arts, vol. iv., p. 226,) consists "in causing the smoke or flame of the fresh fuel to pass, together with a current of fresh air, through, over, or among fuel which has ceased to smoke, or which is converted into coke, charcoal, or cinders, and which is intensely hot, by which the smoke or grosser parts of the flame, by coming close into contact with, or by being brought near unto, the said intensely hot fuel, and by being mixed with the current of fresh or unburnt air, are consumed or converted into heat, or into pure flame, free from smoke. I put this in practice by constructing the fire-place in such a manner that the flame and the air which animates the fire must pass downwards, or laterally, or horizontally *through the burning fuel*. In some cases, after the flame has passed through the burning fuel, I cause it to pass through a very hot funnel, flue, or oven before it comes to the bottom of the boiler, by which means the smoke is *still more effectually consumed*." Neglecting the sound, and adopting the unsound, part of Watt's specification, several patents have, of late years, been taken out in the very words of the above. In one of these, by means of double furnaces, one above the other, the gas generated in the upper one is actually forced or drawn down by artificial currents through the ignited fuel in the lower one.

Thus, we see the very words of Watt, where he was in error, have been adopted to express the main, and, in many instances, the only, feature of these smoke-burning patents; while the judicious part of his instructions has been unaccountably omitted.

I need only say, chemistry has since taught, that the whole process is injurious; and that, if the introduction of the *air* be properly managed, the necessary *heat* for effecting combustion will never be wanting in the furnace.

The mere enunciation, then, of a plan for "*consuming smoke*" is *prima facie* evidence, that the inventor has not sufficiently considered the subject *in its chemical relations.* Chemists can understand a plan for the *prevention* of *smoke*, but as to its *combustion*, it is so unscientific, not to say impossible, that such phraseology should be avoided. The popular and conventional phrase, "a furnace burning its own smoke," may be allowed as conveying an intelligible meaning; but, in a scientific work, or from one professing to teach those who cannot distinguish for themselves, and who may thus be led into error, it is wholly objectionable.

SECOND PART.

CHAPTER I.

OF THE PRINCIPLES ON WHICH BOILERS AND THEIR FURNACES HAVE HITHERTO BEEN CONSTRUCTED.

HAVING, in the preceding part of this Treatise, examined the subject in reference to its *chemical* relations, we have now, in this second part, to consider its application *practically*, in the construction of steam-boilers and their furnaces.

It will not be disputed, that before we are in a position to decide on the necessary proportions of any vessel, we should first understand the purposes to which it is destined. Hitherto, although the combustion of bituminous coal is admitted to be of the most complex character, nevertheless, in apportioning the several parts of furnaces in which those operations are to be conducted, the *slide-rule* has too often been allowed to supersede *the rule of chemical equivalents.*

Until the appearance of the first part of this Treatise, in 1841, there was no published work in which the combustion of coal, on the scale of the furnace, was treated with reference to its division into the *gaseous and solid* states, and the requirements peculiar to each. The only consideration appeared to be, the giving the coal "*a free supply of atmospheric air.*" Watt, and others since his time, have acknowledged the practical difficulty of so introducing the air as to effect perfect combustion; still, no consideration has been given to the necessity of providing separate supplies to the constituents of the coal, in their separate states. In laboratory practice (by which we must submit to be instructed) nothing would be considered more anomalous, or even absurd, than dealing with any bodies in nature without giving attention to the nature of their constituent parts respectively; nevertheless, we have patentees affecting to economise fuel, and produce its perfect combustion, yet giving their attention, exclusively, to the several parts of the boiler in their mere *mechanical proportions*. Mechanical details, however, must yield to those of chemistry.

While the enlightened mind of Watt was directed to the employment of Steam as a mechanical agent, in the development of power, we see him also studying the phenomena of nature in the generation and application of heat, concurrently with those mechanical arrangements, by which it was to be made practically available. Instead of limiting his views to mere proportions, he regarded them only as they were—subservient to scientific considerations. He went elaborately into all that belonged to the character and constituents of solid, fluid, and gaseous matter, as far as the very limited chemical knowledge of the time admitted; and it was in the course of these scientific researches that he became the true discoverer of the constituents of water. He examined the laws which governed its temperature and volume; its expansive force as steam; and the measure of that heat which was again to be surrendered under the process of condensation. In every thing we find his comprehensive mind keeping scientific inquiries, and mechanical appliances in view. Here, then, we have a sound and practical course suggested, and under which alone we may hope to bring our labours to a successful issue.

The inquiry before us cannot be confined to a mere comparison of the several descriptions of boilers, mechanically considered. The merits on which, respectively, they rest their claims, must be examined with reference to other data, viz., their relation to the perfect combustion of the fuel employed — the generating the largest measure of heat — and so applying it as to produce the largest volume of steam. Apart from these considerations, indeed, there is little scope for inquiry. All boilers have their furnaces and grate-bars, on which the fuel is placed; their flues, or tubes through which the flame or gaseous products have to pass; and the chimney by which those products are to be carried away, and the necessary draught obtained.

Hitherto, those who have made boiler-making a separate branch of manufacture, have given too much attention to mere *relative proportions.* One class place reliance on enlarged grate surface; another, on large absorbing surfaces; while a third demand, as the grand panacea, "*boiler room enough,*" without, however, explaining what that means. Among modern treatises on Boilers, this principle of *room enough,* seems to have absorbed all other considerations, and the requisites, in general terms, are thus summed up:

1st. Sufficient amount of internal heating surface;
2nd. Sufficiently roomy furnace;
3rd. Sufficient air-space between the bars;
4th. Sufficient area in the tubes or flues; and
5th. Sufficiently large fire-bar surface.

In simpler terms, these amount to the truism—give sufficient size to all the parts, and thus avoid being deficient in any.

So gravely is this question of relative proportions insisted on, that we find many treatises on the use of Coal, and the construction of Boilers, laying down rules with mathematical precision, giving precise formulæ for their calculations; and even affecting to determine the working power of a steam-engine, by a mere reference to the size of the fire-grate, and the internal areas and surfaces of the boiler. Yet, during this apparent search after certainty, omitting all inquiry respecting the processes or operations to be carried on within them.

Among those in which the subject has been treated in the most detailed manner, it will be sufficient to refer to the work of Dr. Lardner, whose illustrations, as a popular writer, have peculiar merit; and whose statements may be considered as a summary of the practice which generally prevails. In his work on "The Steam-Engine," while commenting on "*the want of general principles,*" he falls, unconsciously, into neglect of the very principles on which alone the inquiry should be based. Calling them *principles,* he lays down a series of rules, or *data,* which refer, exclusively, to *mechanical proportions;* but which furnish no guide to the involved operations to be effected by their means. His rules for the construction of Boilers are thus dogmatically laid down.

For every cubic foot of water to be evaporated *per hour,* allow—one square-foot of grate-bar; one square-yard of heating surface; ten cubic feet of water-space; five square-feet of water-surface; ten cubic feet of steam-space.

Here we have all the proportions laid down and squared, according to rule, as if it were the orders of architecture, or the proportions of a building that were under consideration, rather than of vessels, in which complicated chemical processes were to be conducted. These rules, however, will not teach us how best to effect the combustion of any given weight of fuel, or increase the generation, transmission, or absorption, of any given quantity of heat. We have here laid down, *secundum artem,* a scale of internal proportions, but no clue to that of the heat generative effect of a square-foot of grate-bar, or the heat transmitting power of a square-yard on internal surface.

It may, indeed, be asked, what relation a square-foot of grate-bar can have to a cubic-foot of water; or to any given weight of fuel? We know that under different circumstances, treble, or quadruple the amount of these proportions may be beneficially, or injuriously, found in practice; and that even double the weight of fuel may be more advantageously consumed, on a given area of grate-bars, in one class of boilers than could be effected in another.

In truth, the weight of fuel to be consumed has no legitimate relation to the space on which it may be laid, and depends on other considerations, viz., on the quantity of air passing through it, the time employed, and the weight of oxygen taken up by the several constituents of the fuel respectively.

Again, it may be asked, what relation a square-yard of heating surface has to the transmission of any given quantity of heat, or the generation of any given quantity of steam?

It is strange that so astute an observer (for Dr. Lardner does not affect to be an authority), should have omitted all reference to those processes and tests, by which alone a correct estimate could be made of the effective value, chemically or commercially, of any one of the proportions he has given; or the relation they bear to the functions of the furnaces or flues of a boiler. He has given no clue to the *temperature* produced in any part; yet temperature is the very element and measure of efficiency. His calculations, in fact, have no value except in the assumed, but utterly erroneous data, that each square-foot of bar-surface was equivalent to the perfect combustion of a given weight of fuel, and the generation of a given quantity of heat in a given time; and that every square-yard of internal surface must, necessarily, be brought into action, and received as equivalent to the transmission of a given quantity of heat. He has also omitted reference to the influence which internal areas have on the circulation of the water, and the relative volumes of air to be supplied, or of gas generated, consumed, or wasted. Now the magnitudes and quantities which here really require to be calculated are *chemical*, not *mathematical*. They are not those of flue-surfaces, or grate-bars, but of the bodies to be introduced to them, the quantities in which they respectively combine, and the heat evolved, applied, or lost. If these quantities can be expressed in the terms of an equation, let it be given. Let the attempt be made. It cannot fail of being useful, at least in one respect. It will enable the boiler-maker to appreciate the small degree of confidence to which these theories are entitled.

In a modern treatise on the construction and proportions of steam-boilers, we find the slide-rule endowed with extraordinary properties. In illustration of the utter inapplicability of such a mode of proceeding, let us but imagine Professors Brande or Faraday desirous of producing, on a large scale, carbonic acid and water. What would be their reply, if advised, that a practical boiler-maker was the person best qualified, to instruct them as to the relative areas and proportions of the vessels to be employed, and that the *slide-rule* would save them much trouble, inasmuch as it would supply the true principle which should govern those proportions? Yet these processes are identically those which are carried on by the combustion of coal in our furnaces. When, therefore, we see the attention of the practical boiler-maker thus directed to mere mechanical data, can we be surprised that the chemistry of combustion has been virtually ignored, and made to give way to calculations drawn from the *slide-rule*,* as here exemplified.

Setting aside these puerilities, the inquiry must be directed not to the several parts of a Boiler, but to *the purposes and functions* for which each part is to be constructed. Investigations conducted in this spirit, and with the aid which the *eye*, the *pyrometer*, and the *thermometer* supply, would soon indicate, not only what should be done, but what should be avoided; and shew that what was well adapted to one class of boilers or furnaces, or one description of fuel, might chemically, practically, and economically, be the reverse as regarded other classes.

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* "Let S = the effective heating surface in square yards.
F = the area of the fire grate in square feet.
P = the horse power of the boiler.

"Then, using the *inverted slide-rule*, or *common rule with the slide reversed*, it must be set as follows:—

A | Horse Power = P | Fire grate in sq. feet = F
O | Horse Power = P | Heating surface in square yards = S

"Suppose, for example, that we have 16 square yards of effective heating surface in a boiler, with a fire-grate of 25 square feet, and we wish to know the most suitable rate to work the boiler at. Then place S = 16 on O, against F = 25 on A, and looking to the left hand, the first two divisions of the same value that coincide with each other (which are those of 20) represent the horse power, as in the example below.

A | P = 20 | F = 25 sq. feet.
O | P = 20 | S = 16 sq. yards.

"Again, suppose that a boiler is intended to drive a 30-horse engine, but it has only 25 square yards of surface, and the area of the fire-grate is required. Then place 30 = the horse power on O, against the same number on A, and looking to the right hand, you will find, against 25 yards of surface on C, the answer to be nearly 36 square feet upon A for the area of the fire-grate; and in like manner against any number expressing the square yards of effective heating surface on O, you will find the number of square feet of fire-grate most suitable for the given power upon A. In short, the inverted line O represents a table of 30-horse boilers with various quantities of surface, and the line A represents a table of areas of fire-grates corresponding to those surfaces.

A	30	Fire-grates	31	34	36	39
O	30	Surfaces	29	26½	25	23."

CHAPTER II.

OF THE FURNACE, AND THE RELATION WHICH ITS SEVERAL PARTS BEAR TO THE OPERATIONS CARRIED ON WITHIN IT.

In considering the furnace and its appendages, it will be necessary to distinguish the functions of each part separately, to avoid attaching duties, or attributing failure, to any one of them, for which another should be accountable.

In the combustion of bituminous coal we have seen there are two distinct bodies to be dealt with, the one a *solid*, the other a *gaseous* body,—these necessarily requiring distinct processes.

On a charge of coal being thrown into a furnace, the heat by which the distillatory, or gas-generating process is effected, is derived from *the remaining portion of the previous charge*, then in an incandescent state on the bars. This process corresponds with what takes place in the gas works, where the coal *inside* the retorts is acted on by the incandescent fuel *outside* of them. This demand for heat in the furnace is, however, confined to the commencement of the operation with each charge. The heat required for *continued gasifaction* is, or ought to be, obtained chiefly from *the flame itself;* as in the case of a candle, where the gasifaction of the tallow in the wick is derived from *the heat of its own flame.* This operation shews the importance of sustaining a sufficient body of incandescent fuel on the bars; and in particular, when a fresh charge is about to be thrown in. Allowing the fire to run too low, before a fresh charge, must be attended with the same injurious effects as allowing the heat which surrounds the retorts to fall below what would be required for the continuous and uninterrupted generation of gas after they are recharged;—namely, *loss of time and duty;*

the object being, in both cases, to obtain the greatest quantity of gas from a given weight of coal, *in a given time.*

With reference to the proportions of the several parts of a furnace, we have two points requiring attention; first, *the superficial area of the grate,* for the retaining the solid fuel or coke; and, second, *the sectional area of the chamber above the fuel,* for receiving the gaseous portion of the coal.

As to the *area of the grate-bars,* seeing that it is a *solid body,* that is to be laid on them, requiring no more space than it actually covers at a given depth, it is alone important that it be *not too large.* On the other hand, as to the *area of the chamber* above the coal, seeing that it is to be occupied by a *gaseous body,* requiring room for its rapidly enlarging volume, it is important that it be *not too small.* With reference to the areas of the other parts of the boiler, it is manifestly impossible, *à priori,* or with any pretensions to correctness, to lay down specific rules, since the weight of fuel that may be placed, or consumed, on any square foot of such surface, must depend on numerous other contingencies. Indeed, to lay down any inflexible rule of proportions would be as inappropriate as to impose on the chemist certain mathematical formulæ for the shapes or capacities of the vessels employed in the laboratory. So soon as all that belongs to *the introduction of air to the two distinct bodies to be consumed,* (the gas and the coke,) shall have become systematized in practice, the supposed difficulties in the apportioning of sizes and areas will vanish, and the effecting perfect combustion in the *furnace,* will become as much a matter of course, as it now is in our *gas burners.* So long, however, as beginning at the wrong end of the question, we attempt determining the proportions of the several parts of the vessels to be employed, *before we have considered what is to be done within them,* we must continue in our present state of uncertainty.

As to the best proportion for the grate, this will be the easiest of adjustment, as a little observation will soon enable the engineer to determine the extent to which he may *increase, or diminish, the length of the furnace.* In this respect the great desideratum consists in confining that length within such limits that it shall, at *all times, be well and uniformly covered. This is* *the absolute condition, and sine qua non of economy and efficiency;* yet it is the very condition which, *in practice,* is the most neglected. Indeed, the failure and uncertainty which has attended many anxiously conducted experiments has most frequently arisen from the neglect of this one condition.

If the grate-bars be not equally and well covered, the air will enter in irregular and rapid streams or masses, through the uncovered parts, and at the very time when it should be *there* most restricted. Such a state of things at once bids defiance to all regulation or control. *Now, on the control of the supply of air depends all that human skill can do in effecting perfect combustion and economy;* and until the supply of fuel and the quantity on the bars be regulated, it will be impossible to control the admission of the air.*

On this head, it is of every-day occurrence that complaints are made of the introduction of the air being attended with decreased evaporation, or increased consumption of fuel. The complainants, however, should understand that they are themselves the direct cause of these effects, and by mere *inattention to the state of the furnaces.* They overlook the fact, that while they are complaining of the effects produced by the introduction of certain *limited quantities* of air in the *right place,* they allow their firemen to leave much of the furnace grate uncovered; thus affording the shortest and hottest possible route for the introduction, perhaps, of double the volume that could possibly be required. So, if an engineer undertake to irrigate a piece of land, and after having given much consideration to his levels, and the area of his sluices, he finds that the owner had allowed his labourers to introduce such an *excess of water in some other quarter* as to mar the whole process, with what justice would he complain that harm, instead of good, had been effected?

Of the great waste of heat and the consequent reduction of temperature in the flues, arising from the single circumstance of allowing the incandescent fuel, towards the end of the charge, to *run too low*, or be irregularly distributed, the experiment of Mr. Houldsworth, as shewn in the annexed diagram (page 49,) is highly instructive, and merits the most attentive consideration. This experiment was made expressly for the British Association assembled at Manchester, in 1842.

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* This necessarily suggests the importance of feeding the furnace by *mechanical means.* Here, then, is a legitimate direction for the ingenuity of patentees. The principles on which a mechanical feeder should be based will be hereafter considered.

By this diagram it will be seen, that on a charge of 3 cwt. of coal being thrown on the furnace, the temperature in the flue (as indicated by the pyrometer) rose, in 25 minutes, from 750° to 1220°, when it began to fall, and descended to 1040°, *the fuel not having been disturbed during 75 minutes.* At this stage, however, a remarkable change took place. Perceiving the temperature in the flue to have become so low, Mr. Houldsworth had "*the fuel levelled*," that is, had it more equally distributed, and the *vacant spaces covered.* The effect was (as shewn in the diagram) the sudden rise in the temperature from 1040° to 1150°, at which it continued during 10 minutes, when it gradually fell to 850°.

The upper line of the diagram represents range of temperature, air being admitted, on Mr. Williams' plan, behind the bridge.

The lower line of the same represents range of temperature, air being included, common plan.

Two important questions are here raised, viz.—why did the temperature in the flue fall, after 25 minutes, from 1220° to 1040°? and why did it suddenly rise to 1150°?—*nothing whatever having been done, with the exception of this one movement—the having* "*the fuel levelled.*" This movement, however, is the key to the whole,—an increase of temperature of no less than 110° being thus obtained in the short space of 2½ minutes,—not by any addition of fuel, or mere rapid combustion, but merely as the result of having "*the fuel levelled.*" The cause of these remarkable alterations of temperature then were, first, the admission of an *excess of air in irregular and uncontrolled quantities through the uncovered portion of the bars*;—and, second, the mere check put to that evil, by their being more equally covered with the fuel.*

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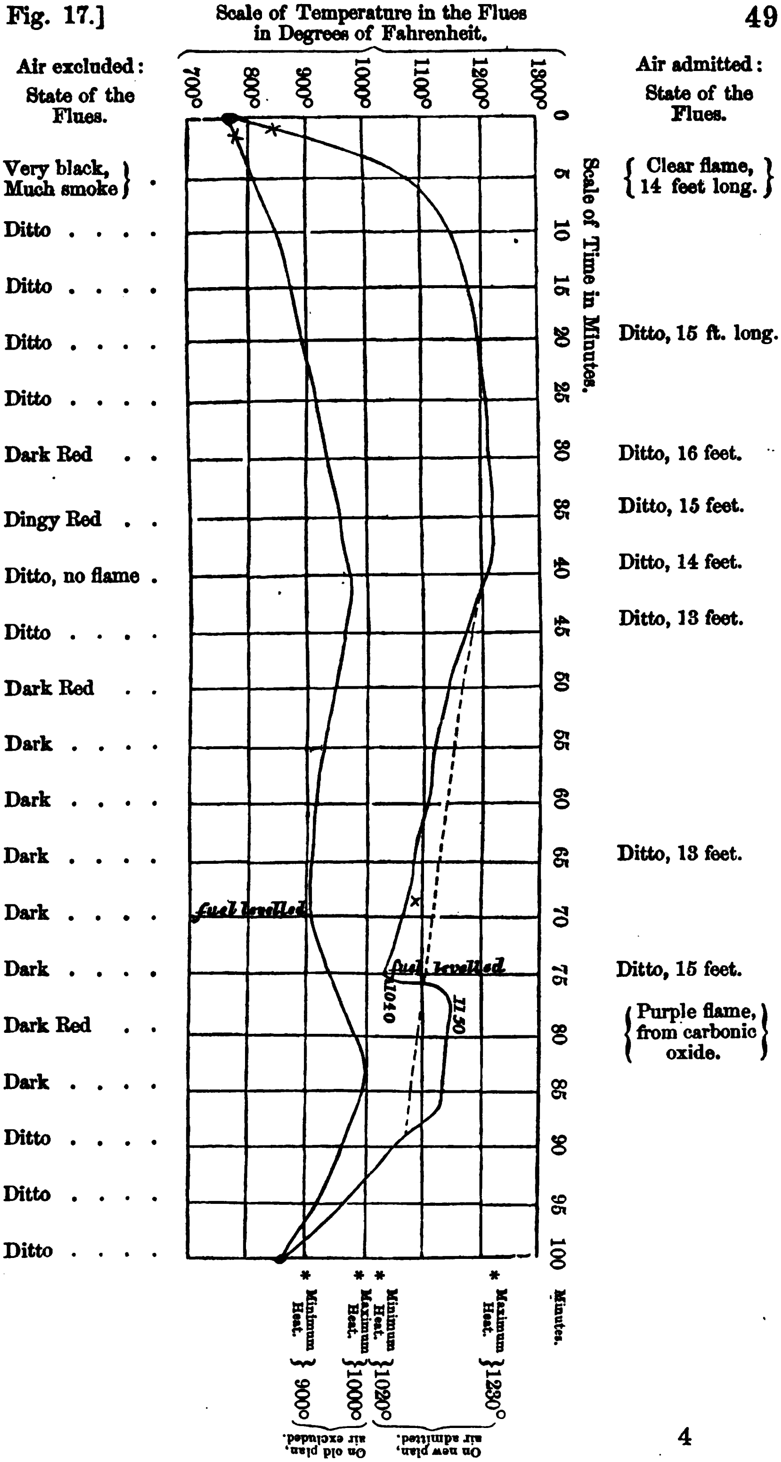
* As the use of the pyrometer is of the highest importance, not merely for experimental purposes but for all boilers, and for general use, whenever it can be introduced, the simple but valuable instrument which is used by Mr.

Fig. 17.]


Scale of Temperature in the Flues in Degrees of Fahrenheit.
700°
800°
900°
1000°
1100°
1200°
1300°
Scale of Time in Minutes.
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
Minutes.
Air excluded: State of the Flues.
Very black, Much smoke
Ditto
Ditto
Ditto
Ditto
Dark Red
Dingy Red
Ditto, no flame
Ditto
Dark Red
Dark
Dark
Dark
Dark
Dark
Dark Red
Dark
Ditto
Ditto
Ditto
Air admitted: State of the Flues.
Clear flame, 14 feet long.
Ditto, 15 ft. long.
Ditto, 16 feet.
Ditto, 15 feet.
Ditto, 14 feet.
Ditto, 13 feet.
Ditto, 13 feet.
Ditto, 15 feet.
Purple flame, from carbonic oxide.
fuel levelled
fuel levelled
1040
1150
* Minimum Heat. } 900°
* Maximum Heat. } 1000°
On old plan, air excluded.
* Minimum Heat. } 1020°
* Maximum Heat. } 1230°
On new plan, air admitted.

It is here to be observed that when a charge is nearly exhausted, or begins to *burn in holes*, the evil increases itself by the accelerated rapidity with which the air enlarges the orifices

Houldsworth, and by which he obtained the above results, is here given from an interesting paper on "The Consumption of Fuel and the Prevention of Smoke," read before the British Association by William Fairburn, Esq., C.E., F.R.S.

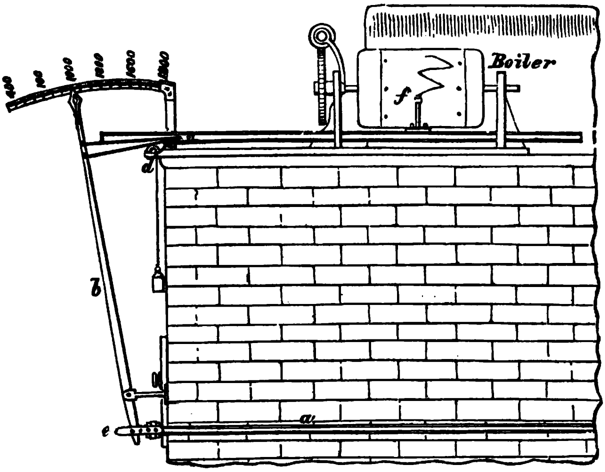
"For these experiments we are indebted to Mr. Henry Houldsworth, of Manchester; and, having been present at several of the experiments, I can vouch for the accuracy with which they were conducted, and for the very satisfactory and important results deduced therefrom.

"In giving an account of Mr. Houldsworth's experiments, it will be necessary to describe the instrument by which they were made, and also to shew the methods adopted for indicating the temperature, and the changes which take place in the surrounding flues.

"The apparatus consists of a simple pyrometer, with a small bar of copper or iron (*a* in the following sketch) fixed at the extreme end of the boiler, and projecting through the brick-work in front, where it is jointed to the arm of an index lever *b*, to which it gives motion when it expands or contracts by the heat of the flue.

PYROMETER.

Fig. 18.



"The instrument being thus prepared, and the bar supported by iron pegs driven into the side walls of the flue, the lever (which is kept tight upon the bar at the point *e* by means of a small weight over the pulley at *d*) is attached, and motion ensues. The long arm of the lever at *d* gives motion to the sliding rod and pencil *f*, and by thus pressing on the periphery of a slowly

it has thus made for its own admission, causing a still more rapid combustion of the fuel around the uncovered parts, and at the very time when these orifices should have been closed.

revolving cylinder, a line is inscribed corresponding with the measurements of the long arm of the lever, and indicating the variable degrees of temperature by the expansion and contraction of the bar. Upon the cylinder is fixed a sheet of paper, on which a daily record of the temperature becomes inscribed and on which are exhibited the change as well as the intensity of heat in the flues at every moment of time. In using this instrument it has been usual to fix it at the medium temperature of 1000°, which, it will be observed, is an assumed degree of the intensity of heat, but a sufficiently near approximation to the actual temperature for the purpose of *ascertaining the variations which take place in all the different stages of combustion consequent upon the acts of charging, stirring, and raking the fires.*"

Mr. Fairburn then gives two interesting diagrams exemplifying the result of experiments made by the aid of the pyrometer, and continues—

"On a careful examination of the diagrams, it will be found that the first was traced without any admixture of air, except that taken through the grate-bars; the other was inscribed with an opening for the admission of air through a diffusing plate behind the bridge, as recommended by Mr. C. W. Williams. The latter, No. II., presents very different figures: the maximum and minimum points of temperature being much wider apart in the one than the other, as also the fluctuations which indicate a much higher temperature, reaching as high as 1400°, and seldom descending lower than 1000°, giving the mean of 1160°.

"Now, on comparing No. II. with No. I., where no air is admitted, it will be found that the whole of the tracings exhibit a descending temperature, seldom rising above 1100° and often descending below 900°, the mean of which is 975°. This depression indicates a defective state in the process, and although a greater quantity of coal was consumed, (2000 lbs. in 396 minutes in the No. II. experiment, and 1840 lbs. in 406 minutes in No. I.,) yet the disparity is too great when the difference of temperature and loss of heat are taken into consideration. As a further proof of the imperfections of No. I. diagram, it is only necessary to compare the quantities of water evaporated in each in order to ascertain the difference, where in No. I. experiment 5.05 lbs. of water are evaporated to the pound of coal, and in No. II. one-half more, or 7.7 lbs. is the result.

"Mr. Houldsworth estimates the advantages gained by the admission of air (when properly regulated) at 35 per cent., and when passed through a fixed aperture of 43 square inches, at 34 per cent. This is a near approximation to the mean of five experiments, which, according to the preceding table, gives 33½ per cent., which probably approaches as near the maximum as can be expected under all the changes and vicissitudes which take place in general practice."

Here are practical results from unexceptionable quarters, and although they have been so many years before the public, nevertheless, smoke burning observations and hot air fallacies continue to be listened to, and dearly paid for.

Had it been possible, in Mr. Houldsworth's experiment, to have preserved the fuel continuously, and *uniformly spread*, throughout the charge of 100 minutes, the diagram would have indicated a more uniform line of temperature, as *marked by the dotted line*, and, consequently, have produced a higher average range of heat in the flue.

M. Peclet,* in his elaborate work appears to have given much attention to the necessity of having the fuel on the bars at all times, in the most uniform state, and thus avoiding any irregular or excessive local admission of air.

With reference to the rate of combustion, and the weight of fuel to be laid on each square foot of bar-surface, this continues to be a debated point. Mr. Craddock, in a late publication (*On the Chemistry of the Steam Engine, practically considered,*) observes:—"There would be no great difference in the steam-generating efficiency of a large grate-surface and a slow draught, or a small grate-surface and a very quick draught; as in our present locomotives."

No correct inference, however, can be drawn from this statement, as he has omitted to explain what is meant by the term "*efficiency.*" Whether it has reference to the *fuel* employed, or the *time* employed:—to the *weight of water* evaporated by a given weight of fuel, or *the time occupied* in producing that effect. *Slow combustion* will be most economical as regards the *fuel employed,* as in the Cornish boilers; while *quick combustion* will be most so as regards the *time employed*, as in the locomotive and marine boiler. As the *weight of the water* evaporated is in the one case over-rated, so the *time employed* is *under-rated* in the other. The mean between the two false estimates will then be the true exponent of the relative commercial value of the two operations.

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* "To produce a good and useful effect, furnaces should, at all times, burn the same quantity of fuel, since the variations in the consumption, caused by the use of dampers, which cannot be made to follow the variations *in the thickness of the bed of fuel,* always cause the passage of a large volume of air that would be unnecessary for combustion."

Again he observes,—"I am convinced, that in a great number of steam-boilers, more than a third of the heat is lost, principally by the introduction of too great an excess of air. It is evident, that to this circumstance may be attributed the singular fact observed by many Engineers,—that in certain descriptions of boilers, the effect produced by the surfaces which are heated by *contact* with the burnt air, (as in the tubes) is but one-third part of that produced by those surfaces which are heated by *radiation*, as in the fire-box or furnace."—*Traité de la Chaleur, considerée dans ses Applications, par E. Péclet, Inspecteur General de l'Université, appliquée aux Arts à l'Ecole Centrale, &c., Paris.*

The view of the subject, as stated by Mr. Craddock, is certainly not supported in practice. By spreading fuel over "a very large surface," the facilities are increased for the admission of a local and wasteful excess of air in numerous small, but aggregately large, quantities, the injurious effect of which *in the flues* cannot be too strongly enforced, as was so clearly demonstrated in the pyrometer experiment of Mr. Houldsworth.

It is true, by these mechanical contrivances, by which the fuel is thinly and continuously spread over a large surface, there would be less tendency to the formation of dense smoke, because the quantity of air introduced over that extended surface, being so much greater than is chemically required, the volume of flame is considerably reduced, and, consequently, the volume of smoke.* We must not, however, deceive ourselves in this matter. The avoidance of dense smoke by these means must be attended with the production of less available flame and heat, relatively with the area on which the fuel is spread, from the extended and attenuated temperature in the furnace chamber. [The relative merits of these mechanical contrivances will be examined in their proper place.]

Many trustworthy manufacturers, having tried the system of revolving grates, moving bars, and self-acting feeders, and having found them unaccompanied with the nuisance of smoke, are hence led to infer that they have produced perfect combustion of the fuel, and economy in its application. This error will be commented on in the succeeding chapters. Without derogating from the merit due to such inventions, mechanically and practically considered, it will, however, be found that these, and such appliances, are but expedients for avoiding the consequences of the first error, namely, the *neglect of supplying the gaseous products of the coal with its proper quantity of air in the right way*. In a word, having first made a serious blunder, we endeavour to escape its consequences by ingenious and even costly contrivances, and actually bestow on them the merit of having rightly worked out the ends and processes of nature. Yet, with equal truth might we designate the nostrums of quacks as the true means of securing a healthy state of body, while they were but so many palliatives of the effect of previous or habitual errors.

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* A familiar illustration of this may be seen in the flame of a candle. If we walk gently, carrying a candle, the current of air induced by our motion cools the flame. The upper part then becomes red, and is converted into a stream of smoke. If, however, we walk briskly along, that elongated lurid flame becomes suddenly short, clear, and without smoke. This change arises from the great access of air to which the flame was then exposed. This is precisely the effect produced by introducing an excess of air through an extended, but thin, body of fuel on the bars.

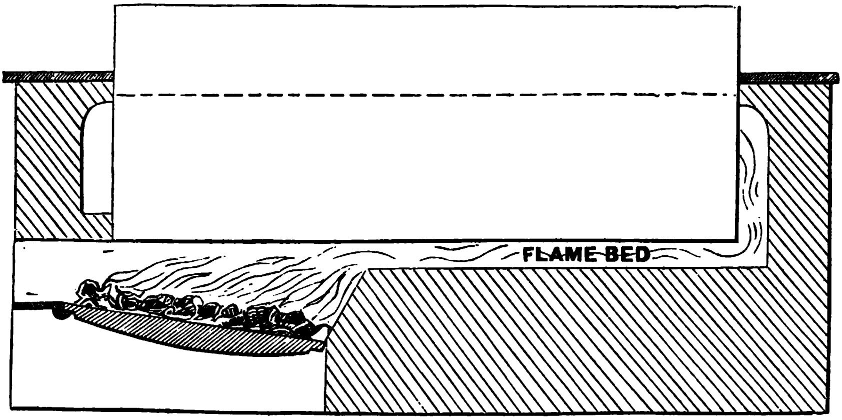
Having spoken of the *grate-bar surface*, and what is placed on it, we have next to consider the *chamber part* of the furnace, and what is formed therein. In marine and cylindrical land boilers, this chamber is invariably made *too shallow and too restricted.*

The proportions allowed are indeed so limited as to give it rather the character of *a large tube*, whose only function should be, the allowing the combustible gases to *pass through* it, rather than that of *a chamber*, in which a series of consecutive chemical processes were to be conducted. Such furnaces, by their diminished areas, have also this injurious tendency,—that they increase the already too great rapidity of the current through them. The defect of insufficient capacity in the chamber of the furnace, above the fuel, will be best appreciated when we consider that in it the gases are generated,—their constituents separated,—each brought into contact with the oxygen of the air,—and, finally, their combustion effected.

The constructing the furnace chamber so shallow, and with such inadequate capacity, appears to have arisen from the idea, that the nearer the body to be heated was brought to the source of heat, the greater would be the quantity received. This is no doubt true when we present a body to be heated in front of a fire. When, however, the approach of the colder body will have the direct effect of interfering with the processes of nature, (as in gaseous combustion,) it must manifestly be injurious. *Absolute contact* with flame should be avoided where the object is *to obtain all the heat* which could be produced by the combustion of the entire of the constituents of the fuel.*

When, however, the object is merely to raise a body to a high temperature by local application, as when we heat a bar of iron in a forge, or a flame, and without reference to the quantity of heat produced and wasted; in such cases, direct contact becomes necessary. So much, however, has the supposed value of near approach, and even impact, prevailed, that we find the space behind the bridge, frequently made but a few inches deep, and bearing the orthodox title of the *flame bed,* as in Fig. 19. Sounder views, however, have shewn that it should have been made capacious, and the impact of the flame avoided. This will be enlarged on hereafter.

Fig. 19.



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* On this point Dr. Ure observes, " When a boiler is set over a fire, its bottom should not be set too near the grate, lest it refrigerate the flame, and prevent that vivid combustion of the fuel so essential to the maximum production of heat by its means. The evil influence of leaving too little room between the grate and the copper may be illustrated by a very simple experiment. If a small copper or porcelain capsule, containing water, be held over the flame of a candle a little above its apex, the flame will suffer no abatement of brightness or size, but will continue to keep the water briskly boiling. If the capsule be now lowered *into the middle of the flame,* this

So little attention has been given to this part of the subject, that we find the practice adopted in *locomotive furnaces* is directly at variance with that in *marine and land boilers.* In *marine* furnaces, using bituminous coal, and where, for chemical reasons, large capacity in the chamber is an absolute essential, it is, nevertheless, made *shallow, narrow, and long.* In *locomotives,* on the contrary, where no similar gaseous operations are carried on, the chamber (called the fire box) is *deep, wide,* and *short.* Thus the former is deficient in the capacity which is there an essential; while the latter has it in abundance, though not absolutely necessary.

This anomaly is illustrative of the absence of due inquiry when the *locomotive tubular system* was inadvertently introduced into marine boilers, as will be shewn hereafter. It is here only necessary to add, that as bituminous coal cannot efficiently, or economically, be employed, except on the condition that the *gaseous* as well as the *fixed portion* be supplied with the air necessary for combustion; so it is essential that adequate space, or area, be provided in the furnace for the due performance of such duties.

As a general rule, deduced from practice, it may be stated, that the depth between the bars and the crown of the furnace should not be less than *two feet six inches* where the grate is but four feet long; increasing in the same ratio where the length is greater: and, secondly, that the depth below the bars should not be less, although depth is not there so essential either practically or chemically.

will immediately lose its brightness, becoming dull and smoky, covering the bottom of the capsule with soot; and owing to the imperfect combustion, though the water is now surrounded by the flame, its ebullition will cease."

CHAPTER III.

OF THE INTRODUCTION OF THE AIR TO THE *COKE*, OR FIXED PORTION OF THE COAL IN A FURNACE, PRACTICALLY CONSIDERED.

WITH reference to the volume of air required for the combustion of the *coke* of a ton weight of coal, independently of the *gas*, there can be neither doubt nor difficulty. There is but one body, or combustible, to be dealt with, viz., the *carbon :* so there is but one supporter of combustion required — the *oxygen of the air.* Any difficulty that may arise, therefore, in practice, cannot be a chemical one, and must be the result of some impediment mechanically introduced.

We have seen that in combustion, atmospheric air is the largest ingredient; yet, it is just the one to which, *practically*, the least attention is given, either as to quantity or control. This surely is not in accordance with the scientific *status* of the age. Indeed, the practice of the present day is in direct opposition to what science dictates; and may be compared to that of a chemist, who, though requiring precise proportions and equivalents, both in weight and volume, of two ingredients, for producing a given result, should nevertheless be particular as to providing the *one*, but regardless as to the *other*.

Mr. Craddock, with the view of refuting the objections to the tubular boiler, observes, " If chemistry did not teach us that the rate of combustion produced in the furnace is dependent on *the quantity of air passing through it*, every day's experience would soon convince us of this." Now, chemistry certainly does not teach, nor does experience justify, any such inference. What both teach is this, that combustion depends not on the quantity of air passing through it, but *on the weight of oxygen which is taken up* in the passage. In truth, the quantity of air passing through it may be even destructive of combustion, when in excess of the demand of the fuel, if improperly introduced.

Again, he observes, "This being the case, the matter stands thus:—the quantity of heat generated is dependent upon the quantity of air admitted: so also is the quantity of steam produced dependent upon the greater or less intensity of the fire."

Neither chemistry nor experience justify these inferences. The quantity of "heat generated" is dependent on the relative weight of hydrogen first, and carbon afterwards, *chemically combined* with their equivalent weights of atmospheric oxygen. The quantity of air admitted may, indeed, actually diminish the quantity of heat generated. So, "the quantity of steam produced" does not depend on the "intensity of the fire," but on the quantity of heat absorbed *by the water*, as will hereafter be explained.

Were there nothing else requiring attention, in the use of coal, than the combustion of its fixed *carbon*, (as in the fire-box of a locomotive) nothing further would be necessary than the supplying the air through the grate-bars to the fuel on them. In the use of *coal*, however, as there is *the gas* also to be generated and consumed, any excess of air, or its injudicious introduction, though it might not affect the combustion of the carbon, must necessarily interfere with the quantity introduced for the use of that gas.

As to the *quantity* of air chemically required for the *coke*, or fixed portion of the coal, after the gas has been expelled, it has already been shewn that every 6lbs. of carbon requires 16lbs. of oxygen. Now, the volume of atmospheric air which contains 16lbs. of oxygen is estimated at about 900 cubic feet, at ordinary temperature. Taking, then, bituminous coal as containing 80 per cent. of carbon, we have 1600 lbs. of coke (the produce of 20 cwt. of coals) requiring its equivalent of oxygen, and which will be equal to 240,000 cubic feet of air; since, as 6 : 900 : : 16 : 240,000. This great quantity of air required for the exclusive use of the coke *on the bars*, must, therefore, be passed upwards, from the ash-pit, the product being transparent carbonic acid gas, of a high temperature.

In this process no error can be committed. The carbon remains quiescent, and *without combustion* (wholly irrespective of the temperature to which it may be raised), until each atom shall, successively, obtain contact, and combine with its equivalent of oxygen; becoming, as it were, the wings by which it is literally to be carried away, in the shape of carbonic acid. Of itself, and without the aid of such wings, it had no power of movement, escape, or combustion.

The conditions under which *coke* enters into union with oxygen, and the singleness of the process, marks strongly the distinction between its use in the locomotive, and that of *coal* in the marine, or land boiler. In the former, there is but one operation, as here shewn; in the latter, however, there are the several gaseous operations, all of which require systematic management.

In supplying the air to the coke, and to avoid the admission of a larger quantity than is legitimately required for its own combustion, the principal point requiring attention is, the *preserving a uniform and sufficient body of fuel on the bars*, as noticed in the last chapter; thus, to prevent the air passing through the fuel in masses or streams, by which a cooling effect would be produced, injurious to the generation and combustion of the gas. Where anthracite is used, as in the United States, and which is composed chiefly of carbon, the practice is to keep a body of it on the bars of from 7 to 12 inches deep. If this depth of anthracite is advisable, it will hereafter be explained, that a greater depth is requisite with bituminous coal.

CHAPTER IV.

ON THE MEANS OF INTRODUCING AIR TO THE GASEOUS PORTION OF THE COAL.

Having spoken of the air required for *the coke* of a ton of coal, we have now to consider the quantity required for *the gas* of the same. Here we enter, unquestionably, on the most difficult branch of the inquiry.

It has been shewn that each cubic foot of gas requires, absolutely, the oxygen of ten cubic feet of atmospheric air. By the proceeds of the Gas Companies, we learn, that 10,000 cubic feet are produced from each ton of bituminous coal: this necessarily requires no less than 100,000 cubic feet of air. Adding this to the 240,000 cubic feet required for the coke, we have a gross volume of 340,000 cubic feet as the minimum quantity absolutely required for the combustion of *each ton of coal,* independently of that excess which will always be found to pass beyond what is chemically required.

As it continues to be asserted that this great volume of air, might, under management, be introduced *through the fire bars and superincumbent fuel,* the question demands a closer examination. A little consideration, however, will shew, that such a proceeding would be not only opposed to all chemical experience, but that it involves a physical impossibility.

It will not here be necessary to prove, that a body of air could not pass through a mass of incandescent coke, without being deprived of the entire, or a large portion, of its oxygen: as well might we expect that air would pass through the lungs of one human being, and yet contain the necessary quantity of oxygen for the support of life in another.

Before a fresh charge of coal is thrown in, there will, or should be, as already observed, a sufficient body of clear and highly heated coke remaining on the bars. *After* the charge has been made, a large volume of gas will be generated; and, consequently, an equivalent quantity of pure air will be required for its combustion. Now, at this stage of the process, and by reason of the mass of fresh fuel thrown in, the passage of the air through it must then, necessarily, be the most restricted. Thus the smallest quantity of air would be enabled to gain admission, simultaneously, with the greatest demand for it; and the largest generation of gas, simultaneously, with the most restricted means of enabling the air to obtain access. Were there no other considerations, these alone would be sufficient to shew the absolute necessity of *providing some other channel* for the introduction of the air for the gas, and the impossibility of introducing the requisite quantity in that direction.

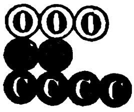
As the obtaining the largest measure of heat from any given weight of coal, turns exclusively on the *introducing the air in the proper quantity and manner*, this, in fact, becomes the cardinal point in the inquiry; and on this point have the greatest mistakes been made. Watt in his early patent (1785) sought to introduce the air *through the body of fresh coal* placed in front of the furnace. Chemistry, however, has since shewn, that not one hundredth part of the required quantity could be so introduced. When Watt was engaged in considering the generation of steam, concurrently with the use and economy of fuel, all was uncertainty as to the proportion of air, chemically required for its combustion. The scientific world had but a vague idea of the relations between the combustible and the supporter of combustion. The all-important system of chemical equivalents which now forms the basis of our knowledge, as to quantities, was not even suspected. Since then, however, by the discoveries of Higgins, Dalton, Davy, and their successors, uncertainty has given way to certainty, and we are now as sure of our results as if we had, physically, the power of handling and combining, at will, the several elements which enter into the composition of bodies. In the language of Stockhardt, "Previously to the discovery of the laws of equivalent proportions, hardly fifty years ago, it could only be ascertained by laborious trials, how much of one body was required to combine with another, or to replace another. It is now only necessary to refer to the table of the proportional or equivalent numbers, to ascertain, and beforehand, the quantity to be employed."

Had Watt been experimenting on the combustion of coal, with the accurate knowledge we now possess, he certainly would not have neglected (as is the case in the present day) the providing the relative quantities of the ingredients, *air being one of them.*

We may here imagine the amazement which Watt would have experienced, had the following formulæ been presented to him.

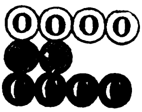
" Organic substances have an incomparably *more complicated constitution* than in the organic compounds, as the following examples shew:

Fig. 20.



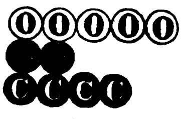
" From the well known amber, a peculiar acid, *succinic* acid, is obtained, which consists of four atoms of carbon, two atoms of hydrogen, and three atoms of oxygen, and has accordingly the formula $C_4 H_2 O_3$ (see Fig. 20).

Fig. 21.



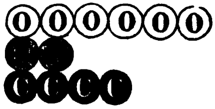
" If one atom of oxygen is added to this, we have the constitution of *malic acid* = $C_4 H_2 O_4$ (see Fig. 21).

Fig. 22.



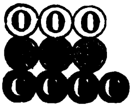
" If one more atom of oxygen is added, that of *tartaric acid* = $C_4 H_2 O_5$ (see Fig. 22).

Fig. 23.



" And by adding yet another atom of oxygen, that of *formic acid* = $C_4 H_2 O_6$ (see Fig. 23).

Fig. 24

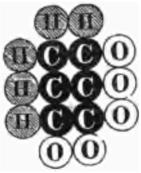


" But on the other hand, if one atom of hydrogen is added to the succinic acid, which was the starting-point, the constitution of *acetic acid* is obtained = $C_4 H_3 O_3$ &c. (see Fig. 24).

"Sugar, starch, and wood have precisely the same constitution, namely, $C_6 H_5 O_5$: they are *isomeric.* If we imagine these three elements grouped together in different ways, as for instance:—

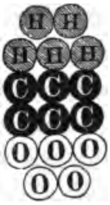
in sugar:

Fig. 25.



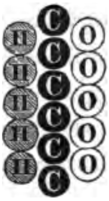
in starch:

Fig. 26.



in wood:

Fig. 27.



"Here, then, we can form an idea how one and the same quantity of the same elements may combine, forming such very different bodies."

With reference to the volume of air to be introduced, Professor Daniell observes, that it will be necessary, even in laboratory practice, to supply *twice the quantity* that would, strictly and chemically, be required. Now, taking the minimum quantity of air, at atmospheric temperature, (for the gas of one ton of coal) at 100,000 cubic feet, to form an idea of what that quantity is, it will only be necessary to say, that it would fill a tube of 12 inches square (the area of ordinary fire doors), and of no less than 20 miles in length. This will enable us to consider practically the great body, or bulk, we have to deal with, and the difficulty of effecting its introduction.

The introducing the required quantity of air will necessarily depend, first, on the *area of the orifice* through which it enters; and secondly, *the velocity* at which it passes through that area. It has been stated that the aperture for the admission of the required quantity should average from *one half,* to *one square inch for each square foot of grate-bar surface.*

So entirely disproportioned, however, is the area here stated, that it would not supply one-fourth the quantity *absolutely required;* much less that additional quantity which we have seen must of necessity pass with it.

There seems, then, to have been some serious oversight in making these calculations. Practice and experiment prove that instead of an area of *one square inch,* no less than *from four* *to six square inches for each square foot* of furnace will be required, according to the gas-generative quality of the coal, and the extent of the draught in each particular case.

In examining the tables of results supplied by experimenters, the cause of their error may be traced to a mistake in the estimated velocity of the heated gaseous matter passing through furnaces to the chimney shafts. As this has, in many instances, been adopted on the supposed authority of Dr. Ure, it is right to state, that the error appears to have originated in taking what that accurate chemist and experimenter had given,—not as *practical*, but as *theoretic* results.*

It is to be observed, that we are not here determining (as Dr. Ure was) the velocity of the current of *heated* gaseous products passing *through the flues of a furnace*, or escaping by a shaft of any given height. It is not the *egress* of intensely heated products that we are considering, but the *ingress* of air at merely *atmospheric temperature* and pressure; and further subject to all the consequences of impeded motion from friction, in passing through numerous small apertures.

The following table of relative velocities of the air on entering, will illustrate the joint influences of current and area through the admission orifices.

Air aperture per square foot of furnace for bituminous coal.	Velocity per *second* of ingress current of air at 60°.	Cubic feet per hour entering through small orifices.	For every ton of Coal in cubic feet.
Square inches.	At ft. per second.	Cubic feet.	Cubic feet.
6	5	7,500	75,000
6	10	15,000	150,000
6	20	30,000	300,000
5	5	6,250	62,500
5	10	12,500	125,000
5	20	25,000	250,000
4	5	5,000	50,000
4	10	10,000	100,000
4	20	20,000	200,000

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* Dr. Ure's statement is as follows:—"The quantity of air passing through well-constructed furnaces may, in general, be regarded as double what is

Now, suppose a furnace measuring 4 × 2/6 = 10 square feet of surface, and with moderate draught, this will be adequate to the combustion of 2 cwt. of coal per hour;—the gas from which will require 10,000 cubic feet of air. To supply that quantity, within the hour, will require the following relative areas of admission, and velocity of current, viz:—

	Velocity of current *per second* of air entering the furnace.			Area of aperture, in square inches, per foot of furnace.	
If at	6.66	feet per second,	will require	6	square inches.
„	10	„	„	4	„
„	20	„	„	2	„
„	40	„	„	1	„

From this we see the absolute necessity of ascertaining the practical rate of current of the air *when entering*, before we can decide on the necessary area for its admission. Hitherto no estimate has been made respecting these proportions on which reliance can be placed.

With reference to the *mode* of introducing the air, it is not a little remarkable, (so slow is scientific progress when opposed to established custom) that many, to the present, overlook, or even dispute the difference in effect, when it is introduced through *one*, or *numerous* orifices. In illustration, then, of the effect of introducing the air *in a divided form*, let us take the case of a boiler furnace of modern and approved form, where

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rigorously necessary for combustion, and the proportion of carbonic acid generated, therefore, not one-half of what it would be were all the oxygen combined. The increase of weight in such burned air of the temperature of 212° being taken into account will give 19 yards or 57 feet per second for the velocity in a chimney 100 yards high incased in steam.

"Such are the deductions of theory; but they differ considerably from practical results." Describing the many sources by which the theoretical velocity was diminished, he gives the result of a series of experiments in which the velocity per second was as follows:—

"The chimney being 45 feet in length, the temperature of the thermometer being 68° Fahr. the velocity per second was—

Trials.	By Theory.	By Experiment.	Mean Temperature of Chimney.
1	26·4 feet	5 feet	190 Fahr.
2	29·4 „	5·76 „	212 „
3	34·5 „	6· 3 „	270 „

the air enters by a *single orifice*, and compare it with that shewn where it enters through 100 or more orifices.

In the first example, (if the body of air be not too great,) the effect may be favorable, to some extent, in preventing the generation of dense smoke. Inasmuch, however, as the quantity of air thus introduced, is chemically inadequate to the combustion of the gas, much of the latter must escape *unconsumed*, though not in the form of smoke, but as a light coloured vapour. In such case, however, the inference usually drawn would be, that the area of admission was sufficient, and the combustion perfect.

This, however, would be erroneous; besides, that it would constitute the mere non-appearance of smoke as the test of perfect combustion of the gas.

Fig. 28.

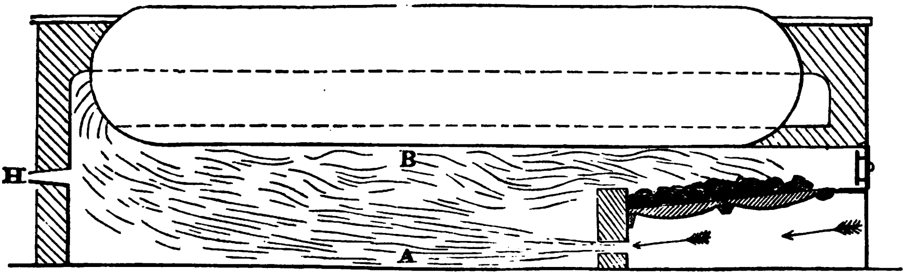


Fig. 29.

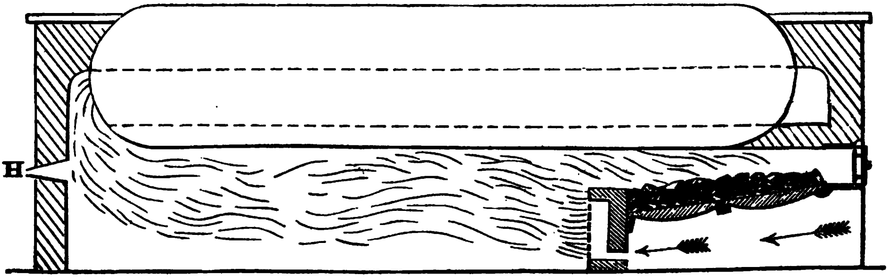
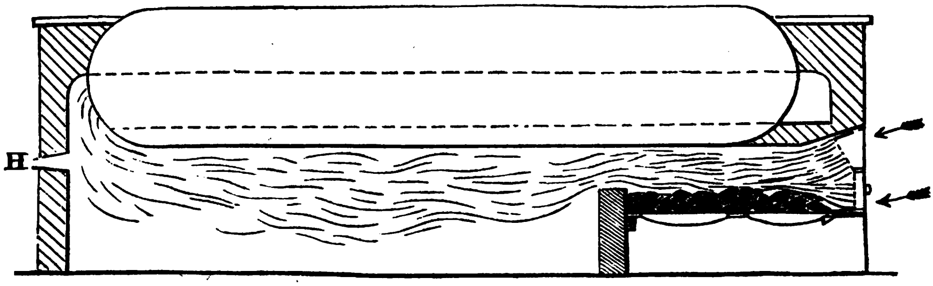


Fig. 30.



In the first case, Fig. 28, the body of air, by passing through a single aperture, produces the action of a strong current, and obtains a direction and velocity antagonistic to that *lateral motion* of its particles which is the very element of diffusion. In this case, passing along the flue, the stream of air pursues its own course at the lower level, A, while the heated products fill the *upper one* at B. It is here evident, according to the laws of motion, that the two forces, *acting in the same direction*, prevent the two bodies impelled by them (the air and the gas) from amalgamating. In fact, they do not come into contact, except in the strata, or planes, of their respective proximate surfaces. The cooling influences of the air, however, goes on in the flue, and produces a result the reverse of what was then most desired. In this case, the velocity of the current is opposed to the desired diffusion; and as, by the laws of motion, matter cannot change its direction unless by the introduction of *some other force ;—that other force* is just what is here required. Thus, in the present instance, we must either change the direction of the current of the air, *or give it the right direction from the beginning.*

Now, instead of a single aperture, let the air enter through a hundred or more apertures, as in Fig. 29. Here the force and direction of *the current* will be avoided, and the required diffusive action produced on passing the bridge. Instead of the refrigeratory influence of the air, as in the first case, there will be a succession of igniting atoms, or groups, which Sir H. Davy calls "explosive mixtures," each producing combustion with its high temperature. These are distinctly perceptible from the sight holes at H.

The same results will follow, whether the single or numerous orifices are placed at the *door*, or at the *bridge end* of a furnace, as in Fig. 30. In this case, the diffusion will be more immediate and effective.

On this point it may be well to notice the oft-repeated fact, that the avoiding dense smoke may be obtained by leaving the fire-door *ajar*. Now, so far from this being a discouragement, or argument against the use of numerous small orifices, it absolutely confirms both the principle and practice; for, if allowing a *given quantity* of air to enter in a thin film at the edge of the door have a good effect, we are thereby encouraged to allow the *entire complement* to enter by other and *more numerous films* or apertures. If, indeed, allowing the door to be *ajar*, with an opening of one inch, were sufficient for the admission of *the entire volume* required, nothing further will be desired. The moment, however, the aperture is enlarged by opening the door wider, to allow that required volume to enter, the injurious and cooling influence of the body and current of air becomes self-evident, and the result confirmed by the reduced temperature in the flue, as indicated by the pyrometer.

Of the advantageous effect produced by *mechanical agency*, in promoting immediate diffusion between the air and the gas, the following experiments are quite conclusive.

Let Figures 31, 32, and 33, represent each a tin apparatus, with its glass chimney, similar to the ordinary Argand burner,—the gas is admitted the same way in all three—the difference to be noted is, *in the manner in which the air is admitted.* In all these cases, the quantity of both gas and air was the same.

In Fig. 31, no air is admitted from below; and the gas, consequently, does not meet with any until it reaches the top of the glass, where it is ignited, producing a dark smoky flame.

In Fig. 32, air is admitted from below, and rises through the orifice at A, concurrently with the gas at the orifice B. On being ignited, one long flame is produced, of a dark colour, and ending in a smoky top.

In Fig. 33, the air is introduced from below, and into the chamber c c., from which it issues through a perforated plate, like the rose of a watering pot; thus producing immediate mixture with the gas. On being ignited, a short, clear, and brilliant flame was produced, as in the ordinary Argand gas burner.

The *heating powers* of the flames were then tested, by placing a vessel of cold water over each. When over Fig. 32, it required 14 minutes to raise the water to 200°, whereas, over Fig. 33, it reached 200° in 9 minutes.

Fig. 31.

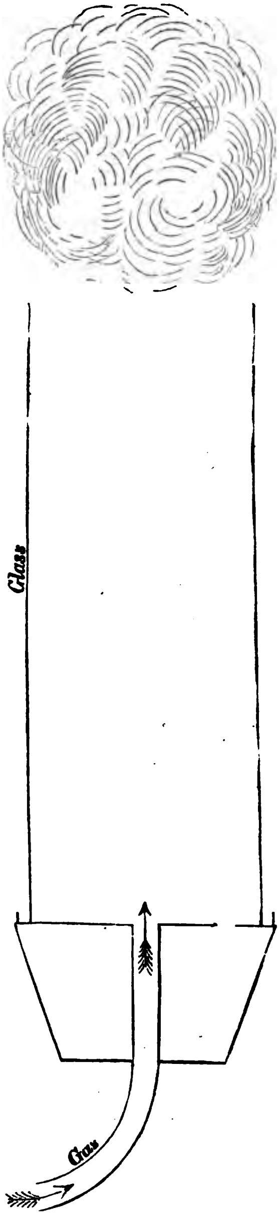


Fig. 32.

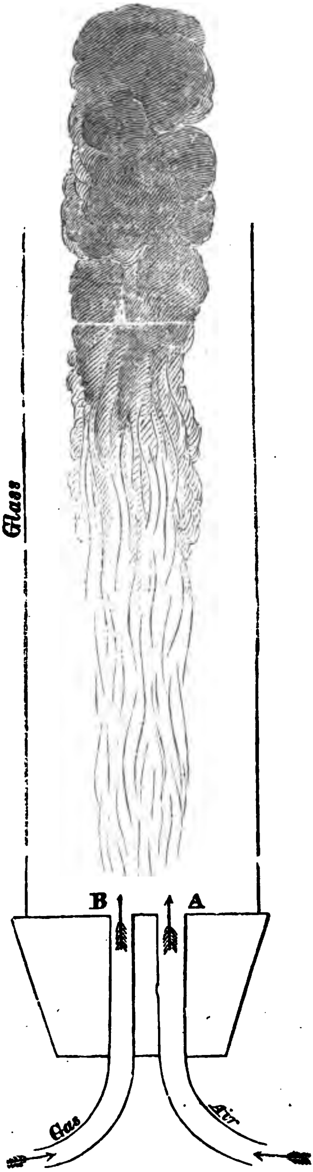
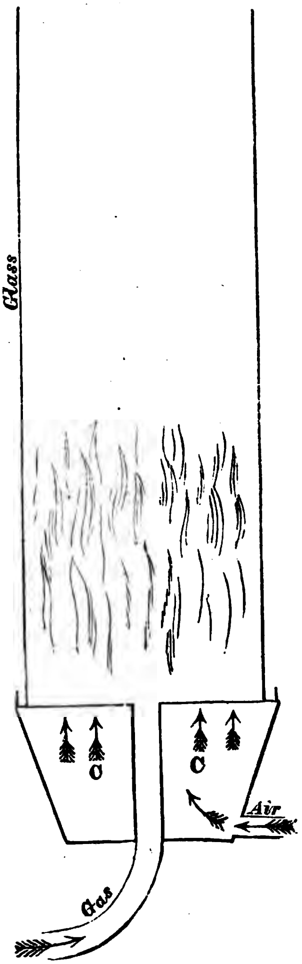


Fig. 33.



Now, the difference of effect produced in those three experiments corresponds with what takes place in furnaces and their flues, when the air is excluded, and when it is admitted through a single or through numerous orifices.

Of the importance of *mechanical agency*, in promoting the rapid diffusion or mixture of the air and the gas, the modes adopted on the continent for rendering the coke gas, or *carbonic oxide*, available, are conclusive and instructive.

M. Peclet has given ample details of the mode of effecting the combustion of this gas, (the existence of which has, for a long time, been practically ignored in this country,) in the manufacture of iron, and even in the puddling furnaces, where the most intense heat is required.

M. Peclet states that the process at Treveray, in France, (see Figs. 34 and 35) is preferable to that adopted in Germany, and for the following reasons, which are quite to the point of our present inquiry.

1st. The air and the gas are better incorporated.

2nd. The relative quantities of the gas brought into contact with the air are more easily regulated.

3rd. Combustion is effected by the introduction of the smallest excess of air.

In the apparatus, as shewn in the section, Fig. 10, 50 jets of air issue, each in the centre of 50 jets of the gas (carbonic oxide), led from the cupolas of the melting furnaces. On examination of the process here exhibited, the mixing and combustion, it will be seen, takes place *on the instant*, and before the flame and heat enter the chamber of the furnace at F. By this arrangement, M. Peclet observes, "that the highest temperature that the arts can require is here obtained." It is strange that the practical and commercial value of this gas, which is so wastefully expended at our manufactories, at the summit of the cupolas, but so well understood, and economized in France and Germany, is only just now being recognized in this country.

Fig. 34.

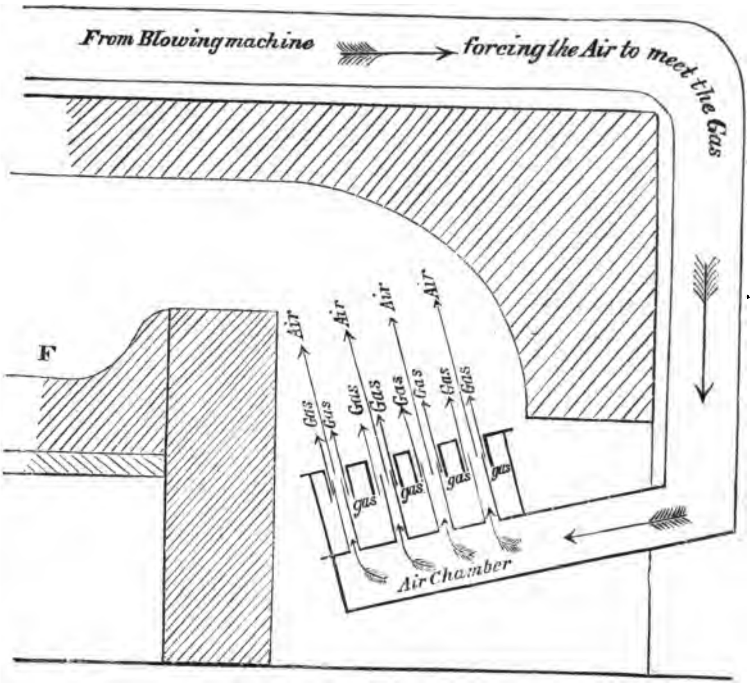
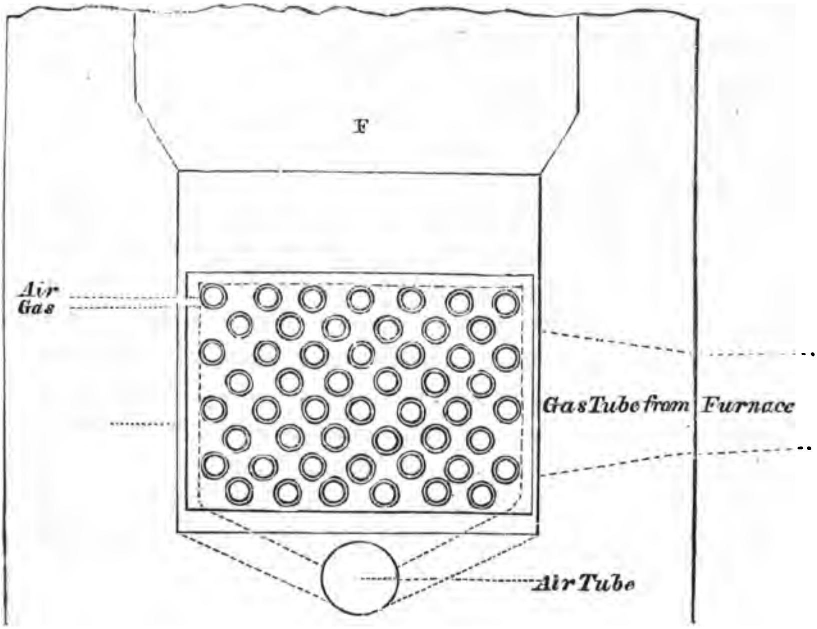

From Blowing machine
forcing the Air to meet the Gas
F
Air
Air
Air
Air
Gas
Gas
Gas
Gas
Gas
Gas
Gas
Gas
gas
gas
gas
gas
Air Chamber

Fig. 35.


F
Air
Gas
Gas Tube from Furnace
Air Tube

CHAPTER V.

OF REGULATING THE SUPPLY OF AIR TO THE GAS BY SELF-ACTING OR OTHER MECHANICAL APPARATUS.

MUCH has been urged on the necessity for regulating the supply of air entering the furnace, as a means of preventing an excess at one time, or insufficient quantity at another. The theory is plausible. Practice, however, when tested by the aid of a pyrometer, and on the large scale of the furnace, has invariably proved its unsoundness and futility.

If the generation of the gas in a furnace were a *constant* quantity; or uniformly increasing and decreasing; and absolutely ceasing at some one stage of the charge of coal; such regulating apparatus would have its merit. The eye and the pyrometer, however, at once warn us of the wide difference between theory and practice; exhibiting the irregularities in the generation of the gas, and the error of applying an inflexible scale to a series of ever varying quantities.

The possibility, or policy, of regulating the admission of air by *mechanical means,* was the object of numerous efforts on the large scale. The aid of the first mechanical and chemical authorities was directed to ascertain whether any, and what degree of adjustment was practicable or advisable. After much investigation it was found, that under the varying circumstances of land and marine boilers; — of quick and slow combustion;—of large and small furnaces;—of the irregularities of the draught, which often varied, even in the several furnaces of the same boiler: looking also to the various modes of firing, and the uncertain qualities of the fuel employed; all these render the theory of regulating the admission of the air, as *each charge proceeded*, not only impracticable, but even injurious.

In the report made to the Dublin Steam Company, in 1842, by Mr. Josiah Parkes, (the Patentee of the Split-bridge,) an engineer well qualified for such an inquiry, he observes,—"During the above-named experiments,* I made numerous essays of the effect produced by shutting off the admission of air to the gases, after the *visible* inflammable gases had ceased to come over, and when the fuel on the grate was clear and incandescent. *In such cases I always found the entire stoppage of air to be followed by diminished heat in the flues and by diminished evaporation;* for at these times, *carbonic oxide* continued to be formed; a gas which, though colourless, was converted, by a due mixture of the atmospheric air, into flame, possessing, evidently, a high intensity of heat, and producing much useful effect. The calorific value of this gas is lost *when the air is excluded,* although its non-combustion is not attended with the production of visible smoke."

During these investigations it was ascertained, that *the appearance or non-appearance of visible smoke* was no test, either for or against the admission of air—*as to quantity.* Mr. Parkes on this head observes:—"The consequences of regulating and varying the quantity of air admitted so as to suit the varying state of the furnace, as regards the quantity of gas given off, also occupied my close attention. It is quite certain that, to effect the perfect combustion of all the combustible gases produced in a furnace, a large demand for air (distinct from the air entering the grate) *always exists:* also, that by entirely *excluding air,* smoke is produced, and the heat diminished in all states of the fire. Thus, with correctly assigned proportions once ascertained, no attention is required on the part of the fireman in regulating the admission of air. On looking through the sight holes, it was manifest, that, as a stream of either carburetted hydrogen, or carbonic oxide gas, was at all times generated and passing over; so there was necessarily a corresponding demand for air; and when supplied, a continuous stream of visible flame."

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* These experiments were made with great care and deliberation, and with all the aids that the eye, the pyrometer, and the thermometer could give. Every part of the interior was always visible, and closely attended to; the temperature in the flues and the heat of the escaping products in the chimney were also watched and noted.

This is conclusive on the point of regulating the supply of air, or shutting it off at any period of a change.

In addition to this inquiry, Sir Robert Kane (one of the highest chemical authorities of the day), was also engaged, and made an elaborate investigation and report on the subject.

REPORT TO THE DIRECTORS OF THE CITY OF DUBLIN STEAM-PACKET COMPANY.

Gentlemen, — In accordance with your request, that we should proceed to examine into the construction and performance of the Marine Boiler Furnaces erected at your works in Liverpool, upon the principle of the patent of Mr. Williams, we have to report, that we have carefully inspected the operation of these furnaces in their several parts, and also some others constructed in a similar manner, upon a large working scale, which are now in actual use in various parts of the town; and that we have instituted several series of experiments and observations upon the temperature produced by those furnaces, and the manner in which the fuel is consumed in them.

In deducing from those experiments and observations the conclusions which will be found embodied in this report, we have taken into careful consideration the general chemical principles upon which combustion must be carried on, so as to effect the greatest economy of heat and fuel; and we have examined how far those principles are attended to in the construction of the various kinds of furnaces that have been proposed for practical use.

The conclusions to which we have arrived, and which we believe to be established by very decisive evidence, as well of a practical as of a theoretical kind, may be briefly expressed as follows:

1st. That, in the combustion of coals, a large quantity of gaseous and inflammable material is given out, which, in furnaces of the ordinary construction, is, in great measure, lost for heating purposes, and gives rise to the great body of smoke which, in manufacturing towns, produces much inconvenience.

2nd. That the proportion which the *gaseous* and volatile portion of the fuel bears to that which is *fixed*, and capable of complete combustion on a common furnace grate, may be considered as *one-fourth*, in the case of ordinary coal.

3rd. That the air for the combustion of this gaseous combustible material cannot, with advantage, be introduced either through the interstices of the fire bars, or the door by opening it. In the former case, the air is deprived of its oxygen by passing through the solid fuel, and then only helps to carry off the combustible gases before they can be burned; and, in the latter case, the air which would enter, by reason of its proportionate mass, would produce a cooling influence, and cannot conveniently be mixed so as properly to support the combustion of the gases.

4th. That the combustion of the gaseous materials of the fuel is best accomplished by introducing, through a number of thin or small orifices, the necessary supply of air, so that it may enter *in a divided form*, and *rapidly* mix with the heated gases in such proportions as to effect their complete combustion.

5th. That, in burning *coke*, or when coal has been burned down to a *clear red fire*, although the combustion on the grate may appear to be perfect, and little or no flame may be produced, and no smoke whatever made, *there may yet be a great amount of useful heat lost*, owing to the formation of *carbonic oxide*, which, not finding a fresh supply of air at the proper place, necessarily passes off unburned.

6th. That under the common arrangements of boiler furnaces, where there is intense combustion on the *fire-grate*, and but little in the *flues*, the differences of temperature in and around the various parts of the boiler are greater; and, consequently, the boiler is most subject to the results of unequal temperatures. On the other hand, when the process of combustion is spread through the flues, as well as over the fire-grate, the temperature remains most uniform throughout, and the boiler and its settings must be least liable to injury.

7th. That the heat produced by the combustion of the inflammable gases and vapours from the fuel, in flues or chambers behind the bridge, must be considerable, and can be advantageously applied to boilers, the length of which may be commensurate with that of the heated flues.

In further substantiation of these conclusions, we will describe the results of our experiments made with the marine boilers fitted up with air-apertures on Mr. Williams's plan, in order to determine how far, in practice, the scientific principles of combustion may be economically carried out.

EXPERIMENTS WITH COAL.

EXPERIMENT 1.

When the fire was charged with *coal*, and air admitted only in the ordinary way, (the passage to the air-distributors being closed,) the entire interior of the flues was filled with a *dense black smoke*, which poured out from the orifice of the chimney in great quantity, and as observed through the sight-holes. The mean temperature of the flues in this experiment being found to be 650°.

EXPERIMENT 2.

The furnace being charged in the same manner with coal, and the supply of air by the dividing apparatus fully let on, the smoke instantly disappeared. Nothing visible passed from the chimney. The flues became filled with a clear yellow flame, which wound round at a maximum distance of thirty feet, and the mean temperature at the turn of the flue was found to be 1211°.

Hence, the quantity of heat conveyed to the water through the flues, was nearly doubled by introducing the air in this divided manner; and, whilst the fuel remained the same, the combustion was rendered perfect, and no smoke produced.

Experiment 3.

The furnace being charged with coal exactly as before, the passage to the air-apertures was *one-half* closed. A grey smoke issued from the chimney. The flues were occupied by a lurid flame, occasionally, of nearly forty feet in length; the mean temperature of the flues being found to be 985°.

Thus, with half the supply of air, a mean condition was obtained between the dense black smoke and imperfect combustion of the first experiment, and the vivid combustion and perfect absence of smoke of the second.

EXPERIMENTS WITH COKE.

Having thus tested the circumstances of the combustion of *coal*, under different conditions of the furnace, we next proceeded to ascertain the exact circumstances of the combustion of *coke*.

Experiment 4.

The furnace being fully charged with *coke*, (from the Gas Works,) and the *air-aperture closed*, so that it burned as in an ordinary furnace, the flues were dark, but a bluish yellow flame extended under the boiler to the back, a space of ten feet. The mean temperature of the flue was then found to be 702°.

The *coal*, under the same circumstances, having given a mean temperature of 650°, a difference of 52° heating power was thus shewn in favour of *coke*, and which agrees with results obtained by others with furnaces of the ordinary construction.

Experiment 5.

The furnace being again charged with coke, the air-aperture was opened *one-half*. The flues then became occupied with a flame of various tints, blue, yellow, and rose-coloured, produced by the combustion of carbonic-oxide and various other gaseous products. This flame extended through twenty-five feet. The mean temperature of the flue was then found to be 1010°.

Thus, even with coke, the increase of available heating power, produced by the admission of air on Mr. Williams's plan, was found to be 300°, or three-tenths of the entire.

Experiment 6.

The furnace being again charged with coke, and the air-aperture *fully-opened*, the flame in the flue shortened to about fifteen feet, and the mean temperature of the flue became 852°.

Hence it appeared, that there had been a larger quantity of air admitted in this last case than was necessary for the combustion of the gases from the *coke;* and hence a cooling effect had been produced, such as to neutralize one-half of the advantage which would have otherwise been gained.

It results from these experiments, —

1st. That the air-aperture of the furnace was sufficient for the proper combustion of *coals*, but was one-half too large for *coke*.

2nd. That by the use of the air-apertures, in the case of coals, all smoke is prevented, and the useful effect of the fuel much increased.

3rd. That, even when *coke* is used, the heating effect is also much increased by the admission of air by apertures behind or at the bridge; but it required only *one-half* of the air which is necessary for *coal*. If, however, it be supplied with the quantity best adapted for *coal*, one-half of the advantage is again lost by the cooling power of this excess of air.

4th. Since, in all ordinary cases of practice, fresh fuel is added in moderate quantities, at short intervals of time, it was not found necessary to alter the rate of admission of the air by valves or other mechanism. An uniform current, admitting a quantity of air intermediate to that necessary for coal alone, will abundantly suffice for the perfect combustion of the fuel, and need not require any extra attention on the part of the workmen.

In conclusion, we have to state, as our opinion, that the arrangement of furnace and admission of distributed air on Mr. Williams's plan, fulfils the conditions of complete combustion in the highest degree, as far as is compatible with the varieties which exist in the construction of boilers, the peculiar character of the coal employed, and the nature of the draught; the formation of smoke is prevented; and the economy of fuel we cannot consider as being less than an average of one-fifth of the entire in the case of *coke*, and of one-third of the entire when *coal* is used.

We are, Gentlemen,

Your obedient Servants,

ROBERT KANE, M.D., M.R.I.A.,

Professor of Natural Philosophy to the ROYAL DUBLIN SOCIETY, *and Professor of Chemistry to the Apothecaries' Hall of Ireland.*

R. H. BRETT, Ph.D., F.L.S.,

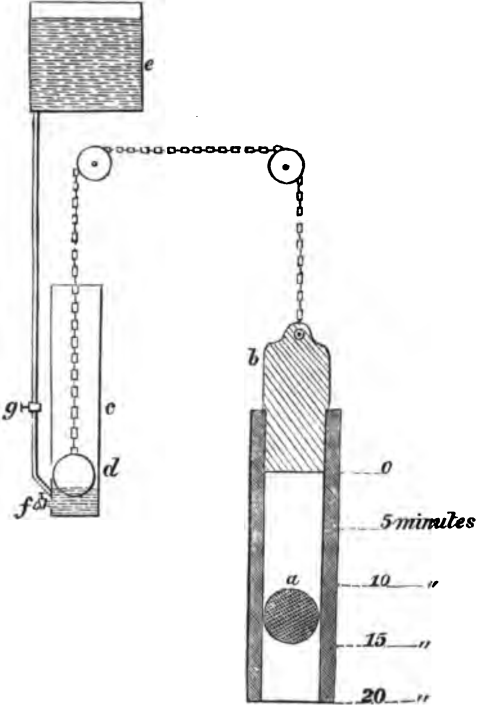
Professor of Chemistry to the Liverpool Collegiate Institution.

The inference from these chemical investigations is, that *there is no interval from the beginning to the end of a charge, when there is not a large body of combustible gas generated in the furnace, and a large supply of atmospheric air required.*

The advocates of self-acting valves have overlooked the chemical fact, that as soon as the coal gas (carburetted hydrogen), ceases to be evolved, the fuel on the bars would then be in an incandescent state, and precisely in the condition to furnish a copious generation of the other gas—the *coke-gas*, or *carbonic oxide;* but which had not hitherto been noticed by any writer *in connection with boiler furnaces.** Now, as this latter gas requires (for equal volumes) one-half the quantity of air of the former, it is equally necessary that such be supplied, or the heating power of carbon would be lost.† The characteristics of this gas have already been given. Its practical application requires here to be noticed.

For obtaining the supposed advantages of regulating the admission of the air by *mechanical agency*, many ingenious contrivances have been suggested. Among these the following was tested many years back by the Dublin Steam Company.

Fig. 36.



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* "Carbonic oxide," observes Professor Graham, "may be obtained by transmitting carbonic acid over red hot charcoal. The combustion is often witnessed in a coke or charcoal fire. The carbonic acid produced in the *lower part of the fire* is converted into carbonic oxide as it passes up *through the red hot embers.*"

† Mr. Dewrance, Engineer of the Liverpool and Manchester Railway, when that fact was pointed out, felt the importance of allowing a large quantity of air to enter through the door, by numerous orifices, and experienced the increased heating powers arising from the combustion of the coke gas in the furnaces of his locomotives.

In the diagram, Fig. 36, *a* is the orifice for the admission of the air; *b* the valve; *c* the cistern with ball to regulate the fall of the valve; *e* the supply cistern; *f* the tap for letting off the water; *g* the tap for regulating the rate at which the valve descends. During the first half of a twenty minutes' charge, the valve has no operation, *the aperture remaining open*, the full supply of air being then required. During the next five minutes it gradually closes, and during the last five minutes remains closed, to counteract the neglect of firemen in allowing too much air to enter through the uncovered bars at the end of each charge.* Simple as this plan was it became unnecessary, and was finally discarded.

As some notoriety has lately been given to the plan patented by Mr. Prideaux, it may here be expected that it should receive examination. Mr. Prideaux very justly observes,†—"Only two methods present themselves by which the supply of air and the wants of the furnace can be made to correspond;—either both must be made constant and regular, or the fluctuations of one must be made to coincide with those of the other." Again, "If a continuous and equable supply is to be furnished to a furnace, then the supply of fuel must be made continuous also. This appears to be the most perfect method of working a furnace, and it is to accomplish this object that most of the attempts to prevent smoke, and obtain perfect combustion, have been directed. Brunton's revolving grate, Jukes' endless chain of fire-bars, and more than one kind of rotary feeder, all fulfil with tolerable efficiency the purposes for which they were designed."

With these just and appropriate remarks Mr. Prideaux introduces his own plan of "*A self-closing valve for preventing smoke and economizing the fuel*,"‡ and by which to cause "*the fluctuations*

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* The adjustment of the action of this closing valve was the result of the changes, as to temperature and effect, indicated by the Pyrometer.

† "*Rudimentary Treatise on Fuel, particularly with reference to Reverberatory Furnaces*, by T. Symes Prideaux, Esq. John Weale."

‡ "A self-closing valve *for preventing smoke, and economizing fuel*," is here a manifest misnomer, inasmuch as the *valve part* of the apparatus has no connection, directly or indirectly, with the *prevention of smoke*, or economizing fuel.

between supply and demand to coincide." He then describes the action of his valve as follows:—"The stoker when he closes the furnace door after firing, will raise the arm of a lever appended to it: this movement throws wide open a sliding valve in the face of the door, which *immediately commences closing*, slowly and automatically, by the gravity of the lever, and affords during the progress of its descent, a gradually *diminishing supply of air to the fire, in harmony with the gradually diminishing requirements of the fuel."*

By what means this hitherto undiscovered phenomenon of the *gradually diminishing requirements of the fuel during the first half of each charge*, was ascertained, is not stated. Now, however plausible this theory may be, it is at once disproved by experiment;—*the "wants of the furnace"* being in direct contradiction to the alleged "gradually *diminishing requirements* of the fuel." In truth, experiment proves, that "to cause *the fluctuations between the supply and demand to coincide*," the arrangements of the valve should have been just the reverse of what is here described as taking place, and should rather require a gradually *increasing* (instead of diminishing) supply of air to the fire, in harmony with the gradually *increasing* (instead of diminishing) requirements of the fuel.

By the operation of closing the valves, the act of diminishing the supply of air begins on a fresh charge of coal being made, and it is entirely closed when one-half the time required for the charge has expired; thus necessarily *remaining shut during the second half,—on the supposition that there was no gas then generated, and no further supply of air necessary.**

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* As this operation of the valve is so directly opposed to the true requirements of the fuel, the patentee's own description of it is here given.

"To give an illustration of its mode of action:—Supposing a fresh supply of coal to be put on a furnace every 16 minutes—the smoke (meaning gas) consequent upon coaling, *to come gradually to an end at the expiration of eight minutes*—and that immediately after coaling, the furnace requires at the rate of 100 measures of air per minute (admitted above the fuel), to furnish the requisite amount of oxygen to prevent smoke.

"For such a furnace as the above, this valve is adjusted, so as to furnish at the rate of 100 measures of air per minute *when wide open, and to gradually close at the end of eight minutes.* Now, as the operation of closing

It is here manifest that the error into which Mr. Prideaux has fallen, has arisen from assuming, theoretically, that the generation of gas, (which he inadvertently calls *smoke,*) would "*come gradually to an end at the expiration of eight minutes,*" from a charge which would take sixteen minutes for its completion. If, indeed, that really were the case, then this action of his valve "gradually closing at the end of eight minutes," would produce perfect harmony between the supply of air and the requirements of the fuel.

The Reports already given by Sir Robert Kane and Dr. Brett, Mr. Parkes, Mr. Houldsworth, and Mr. Fairbairn, being all in direct disproof of the above, render any further remark here unnecessary, except to notice the important difference thus established between theory and practice; and the absolute necessity of proof,—not by the fallacious test of the appearance or non-appearance of smoke, but by ascertaining the temperature in the flue, by the pyrometer, from the beginning to the end of a charge,—and the length, character, and colour of the flame, by actual observation.

Mr. Prideaux proceeds:—"The door of the furnace should be double, and the air should pass into the furnace through a *series of perforations.*" By this arrangement, he observes, "three important points are secured; 1st, the heating the air; 2ndly, the keeping the outer door of the furnace comparatively cool; 3rdly, *its subdivision into minute jets.*"

A few words on each of these three points will here suffice. 1st, Of "*heating the air.*" As Mr. Prideaux takes in the air, as all others do, at mere atmospheric temperature, his claim for "heating the air" goes for nothing. Whatever heat it acquires (and which has been ascertained to be wholly insignificant) can alone be obtained by passing through the perforations in the door plate, as it does in the numerous plans

occupies eight minutes, at four minutes after coaling, the valve is half shut, consequently admitting at the rate of only 50 measures of air per minute, and the whole amount of air admitted in the eight minutes during which the valve is open, will be 400 measures; and this quantity, supplied in a gradually diminishing manner, *in harmony with the gradually diminishing requirements of the fuel,* is found sufficient to prevent all smoke."

hereafter described. [Mr. Prideaux's own authority will hereafter be quoted in proof of the fallacy of the hot-air theory.]

2ndly, As to "*keeping the outer door of the furnace comparatively cool.*" This is too unimportant a circumstance to require further notice.

3rdly, As to passing the air "*through a series of perforations, and its subdivision into minute jets;*" it is only necessary to add, that it is a satisfactory illustration of the principle of the Argand furnace, and of the correct practice enforced in every page of this treatise. Mr. Prideaux has, however, omitted to state that fact, or to disclaim any merit or originality in this, *the only useful part of his patent for "the preventing of smoke and economizing the fuel.*"

Impressed with the importance of the *small jet system*, Mr. Prideaux further adds, "An attempt is often made to mitigate the smoke and imperfect combustion, by *leaving the furnace door ajar* for a certain period after the addition of fresh fuel." To this he correctly objects, on the ground that the air then "enters *en masse*," instead of "*in small jets.*" Numerous other illustrations might here be given as to the efficiency of the "*subdivision into minute jets.*" Mr. Prideaux's evidence in corroboration, is, however, important, although it lays him open to the charge of assuming to be the inventor, or original patentee, of what had long been so well established.*

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* It is here scarcely necessary to say, that had this plan, with this description by the patentee himself, been brought out twelve months earlier, that is, before the expiration of the patent for the Argand furnace, it could not have stood the test of a jury, so identical is the application and description:—"The *series of perforations*, and the *subdivision of the air into minute jets*," being equally applicable to both patents, and conveying, in the most appropriate terms, the very principle and mode of applying the Argand furnace. In fact, the accurate description given by Dr. Ure, (who himself settled the terms of the specification,) furnishes *conclusive evidence of the identity of the two plans.* Dr. Ure (Dictionary of Arts) observes, "The patent of 1839 consists in the introduction of the air through *a number of small orifices, the operation of the air entering in small jets* into the half-burned hydro-carburetted gases over the fires, is their perfect oxygenation." "Again, one of the many methods in which Mr. Williams has carried out the principles of what he justly calls his *Argand furnace*, is represented in the figure." (which he gives.) "The box is *perforated either with round or oblong orifices*, &c." "In some cases the fire-door projects, with an intermediate space, into which the air may be admitted, *in regulated quantity, through a movable valve in the door.*"

With reference to the progressive rate of generation of the gas in a furnace, and the consequent demand for atmospheric air, the length of the flame (when the air is properly supplied) furnishes the best evidence. The following tabular view of the result of numerous accurate experiments, made many years back, and expressly to ascertain the *rate of evolution* of the gases, throughout a charge of 40 minutes duration, is conclusive.

Time.	Thermometric Temperature in Flues.	Length of Flame in Feet.
Charge made	466	10
2 minutes	462	14
4 „	490	18
6 „	508	22
8 „	518	26
10 „	524	26
12 „	528	28
14 „	534	28
16 „	540	28
18 „	540	28
20 „	540	26
22 „	536	24
24 „	524	24
26 „	508	22
28 „	494	22
30 „	486	18
32 „	476	22
34 „	468	14
36 „	464	14
38 „	460	12
40 „	460	10*

We here see, that so far from the quantity of gas generated being *greatest at first*, and ceasing when the charge was one half exhausted, it is just the reverse. In fact, any one who has observed the indications of the pyrometer in the flue, and has looked into a furnace in action, must have observed, that, there being much moisture in the coal to be evaporated, it required a considerable time before the full supply of gas was produced, and the temperature in the flue had risen to the maximum. Further, that when the first half of the charge was exhausted, the greatest quantity of gas was then momentarily evolved;—the longest flame existing in the flue;—and the highest temperature indicated by the pyrometer; consequently, the fullest supply of air was then required.

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* The thermometer bulb was here inserted in the flue, so far as to prevent the mercury rising above 600°—the highest range we see being 540°—when the charge was half expended. The absolute heat in the flue was, however, considerably higher, as ascertained by the melting points of a series of metallic alloys, prepared by Sir Robert Kane, expressly for the purpose. By these, inserted in the flue, it was found that the absolute heat escaping at *the foot of the funnel*, was at least 750°.

The following experiment is also in point here. This was made with a larger charge of coal, and during 60 minutes, (the bars being kept well covered,) the object being to ascertain the relative quantity of *each kind of gas* evolved; and thus form a guide to the quantity of air required, at the several intervals, from the beginning to the end of a charge. [The observations were taken from two sight-apertures: one at the back end of the boiler, and the other at the front, looking into the flue.] When the supply of carburetted hydrogen gas was nearly exhausted, the distinct flames, and their two distinct colours and characteristics, might clearly be distinguished. The following Table will present a view of the relative quantities of the two gases (carbonic acid and carbonic oxide, or coke gas) produced during the progress.

Time in minutes.	Coal Gas.	Coke Gas.	Total length of flame in feet.
Charge of coal	none	10	10
5 minutes	10	none	10
10 „	14	none	14
15 „	18	none	18
20 „	22	none	22
25 „	22	none	22
30 „	18	none	18
35 „	14	none	14
40 „	10	4	14

Time in minutes.	Coal Gas.	Coke Gas.	Total length of flame in feet.
45 minutes	5	8	13
50 „	none	12	12
55 „	none	10	10
60 „	none	10	10

Here column 4 may be taken as indicating the gross quantities of combustible gases evolved, and requiring a supply of air. In numerous other furnaces, in which the air was properly introduced, and the fuel properly covering the bars, the flame was seen during a large portion of an hour's charge, extending along the side flues from twenty to thirty feet. The quantity of the *coke gas* will be in proportion to the thickness or body of the fuel, and its state of incandescence.

With the view of accommodating the supply of fuel to the demand for air, the best practical mode is the *equalizing the quantity of gas requiring such supply.* This was done effectually thirty years back, by arranging the furnaces so that each pair shall be connected with one common flue. This arrangement, for alternate firing, adopted among others in the steamer "*Royal William*" (as hereafter shewn,) is every way satisfactory. A similar arrangement has been introduced in Her Majesty's Steamers "*Hermes,*" "*Spitfire,*" and "*Firefly,*" as described in Tredgold's work; nothing, however, is there shewn as to the means for introducing the air, and, consequently, the value of this flue arrangement is lost.

Fig. 37.

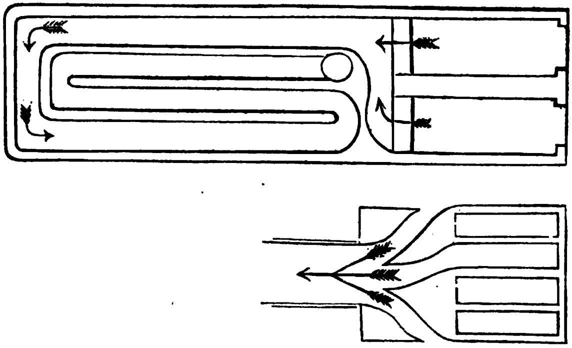

Fig. 37, taken from Peclet's work, shews a similar mode adopted in France, for equalizing the supply and demand of gas and air. It will be manifest that, assuming the furnaces to be charged alternately, the quantity of gas behind the bridge will be the mean of that generated in both furnaces.

Another and a very effectual mode of equalizing the supply of gas, and thus practically equalizing the supply of air, is by charging the furnace-grate alternately, *first on the one side, and then on the other.* Where the furnace is wide enough, this is very effective.

The result of this inquiry into the policy of attempting, by *mechanical means,* to regulate the rate of supply of air to the gas during the continuance of each charge is, that it can be productive of no practical value; and the more so, since, as observed by Mr. Parkes, that " as a stream of either *carburetted hydrogen,* or *carbonic oxide* gas will, at all times, be generated, and passing over, there must necessarily be a corresponding demand for air."

In the report to the British Association, on this very point, Mr. Houldsworth observes, " It has been generally supposed, that when there was a perfectly red fire in the furnace, and when no smoke was generated, the admission of cold air at the bridge would do harm instead of good, by reducing the temperature in the flues. He had, however, tried the experiment that morning. After having the air passages closed for some time, he had opened them when the coals in the fire were perfectly charred, and found an immediate and decided *increase of temperature in the flue.* The increasing temperature was certainly the most striking, if the air passages were opened shortly after a large quantity of fresh fuel had been put on; but, *at all times he found there was an increase when the air was admitted, and a decrease when it was excluded.*"

Practical proof of this kind at once puts an end to the theory of self-regulating valves.

CHAPTER VI.

OF THE PLACE MOST SUITABLE FOR INTRODUCING THE AIR TO THE GAS IN A FURNACE.

HAVING spoken of the necessity of mechanical aid in producing a sufficiently rapid admixture of the air and the gas, we have now to consider of *the place* best adapted for applying this aid.

As regards the *carbon* on the bars, it is manifest that no other place could be selected than directly from the ash-pit. That this is not available for introducing the air to the *gaseous* product of the coal, has now to be considered.

Tredgold contemplated introducing the entire supply of air through the ash-pit and bars, observing that, "the gas which distils from the fresh fuel having to pass over the red hot embers, through which the air in the ash-pit ascends, will be inflamed." Here we have the old error, viz., supposing that passing the gas over red-hot fuel would effect its combustion.

The plan adopted by Mr. Parkes of introducing the air through what is called the *split bridge*, as hereafter shewn, appears to have been among the first which recognized the providing *a separate supply of air* to the furnace gases, independently of that which passed through the fuel on the bars.

This plan was sufficiently effective, when combined with the system of small furnaces, with small charges of coal; or large furnaces when charged heavily, with sufficient fuel for many hours consumption, producing a uniform generation of gas during a long interval, and by the means of slow combustion. The issue of the air through the narrow orifice in the top of the bridge, was, however, found to be unsuited to the large furnaces, with quick combustion, and heavy charges incidental to the boilers used in steam-vessels. It was also liable to be occasionally obstructed by the stronger current of heated products crossing the aperture, in the same way as the ascent of smoke from a house-chimney is obstructed by a strong wind sweeping over it. Numerous modifications of this plan were adopted in steam-vessels, the most important of which will hereafter be given, with the view of explaining the several causes of their failure, and which it is often as important to know as those of success.

When the chemistry of combustion in furnaces was examined in 1841, in the first part of this treatise, it was shewn that the required quantity of air was much greater than had been contemplated by practical men, or stated by any writer on the subject; and that *no single orifice* could be sufficient for the admission of that quantity, unless by introducing it in such volume as would produce a chilling effect on the flame, and a diminished amount of evaporative duty—a fact strangely overlooked in all previous practice.

The arrangement subsequently adopted in several vessels of the Dublin Steam Company admitted the air through numerous apertures, and in a divided state. This mode, which has been clearly described by Dr. Ure in his Dictionary of Arts under the head of "Smoke Nuisance,"* was always effective when the draught was sufficient for the double supply of air, to the fuel in the bars, and the gas in the furnace chamber. The difference which attends its application was often considerable, and arose from the want of draught, or from the perverse adherence to the old and lazy method of charging the front half of the furnaces heavily, even to the doors, while leaving much of the bridge end but thinly covered, as hereafter will be shewn.

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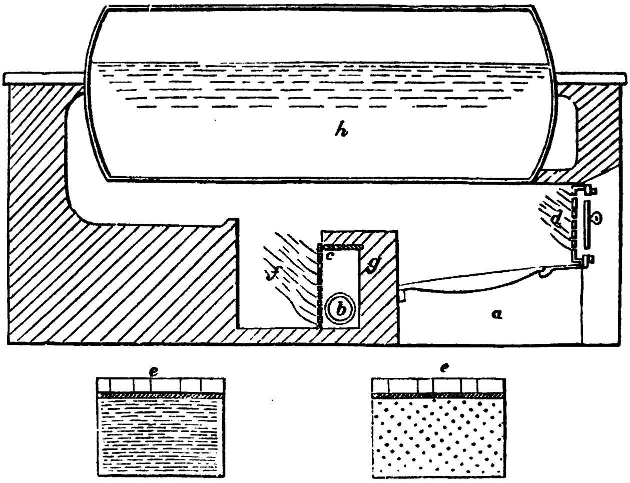
* "*Smoke Nuisance.* Among the fifty several inventions which have been patented for effecting this purpose, with regard to steam-boiler and other large furnaces, very few are sufficiently economical or effective. The first person who investigated this subject in a truly philosophical manner was Mr. Charles Wye Williams, managing director of the Dublin and Liverpool Steam Navigation Company, and he also has had the merit of constructing many furnaces, both for marine and land steam-engines, which thoroughly prevent the production of smoke, with increased energy of combustion, and a more or less considerable saving of fuel, according to the care of the stoker. The specific invention, for which he obtained a patent in 1839, consists in the introduction of a proper quantity of atmospheric air to the bridges and flame-beds of the furnaces through *a great number of small orifices*, connected with a common pipe or canal, whose area can be increased or diminished,

according as the circumstances of complete combustion may require, by means of an external valve. The operation of air thus entering *in small jets* into

Fig. 38.



the half-burned hydro-carburetted gases *over the fires, and in the first flue*, is their perfect oxygenation—the development of all the heat which that can produce, and the entire prevention of smoke. One of the many ingenious methods in which Mr. Williams has carried out the principles of what he justly calls his Argand furnace, is represented at fig. 1310, where *a* is the ash-pit of a steam-boiler furnace; *b* is the mouth of a tube which admits the external air into the chamber, or iron box of distribution *c*, placed immediately beyond the fire-bridge *g*, and before the diffusion, or mixing chamber *f*. The front of the box is *perforated either with round or oblong orifices*, as shewn in the two small figures *e e* beneath; *d* is the fire-door, which may have its fire-brick lining also perforated. In some cases the fire-doorprojects in front, and it, as well as the sides and arched top of the fire-place, are constructed of perforated fire-tiles, enclosed in common brickwork, with an intermediate space, into which the air may be admitted in regulated quantity through a movable valve in the door. I have seen a fire-place of this latter construction performing admirably, without smoke, with an economy of one-seventh of the coals formerly consumed in producing a like amount of steam from an ordinary furnace. Very ample evidence was presented in a late session to the Smoke Prevention Committee of the House of Commons (July 1843) of the successful application of Mr. Williams's patent invention to many furnaces of the largest dimensions, more especially by Mr. Henry

Such a mode of charging the furnaces, necessarily caused an irregular combustion of the fuel, and a consequent excessive admission of air, counteracting all effects at appropriating separate supplies to the coke and the gas.

The introducing the air to land boilers, in numerous films, or divided portions, was first practically adopted in 1841, at numerous furnaces in Manchester,* and at the water-works in

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Houldsworth, of Manchester, who, mounting in the first flue a pyrometrical rod, which acted on an external dial-index, succeeded in observing every variation of temperature produced by varying the introduction of the air-jets into the mass of ignited gases passing out of the furnace. He thereby demonstrated that 20 per cent. more heat could be easily obtained from the fuel when Mr. Williams's plan was in operation, than when the fire was left to burn in the usual way, and with the production of the usual volumes of smoke. *It is to be hoped that a law will be enacted in the present session of Parliament, for the suppression, or at least abatement, of this nuisance,* which so greatly disfigures and pollutes many parts of London, as well as all our manufacturing towns, while it acts injuriously on animal and vegetable life. Much praise is due to Mr. Williams for his indefatigable and disinterested labours in this difficult enterprise, and for his forbearance under much unmerited obloquy from narrow-minded prejudice and indocile ignorance."

It is here worthy of notice, that although the above was written and published by Dr. Ure so many years back, it is now only in 1854 that Parliament have interposed in the manner there suggested.

* It was one of these furnaces that was examined by the Earl of Ellesmere (then Lord Francis Egerton), and which induced his Lordship to write the following letter:—

"Worsley, November 22, 1841.

"SIR,—Having this morning inspected the invention for the prevention of smoke, of which Mr. Charles Wye Williams is the patentee and yourself the agent, I am anxious to bear my testimony to its very palpable success in the attainment of its main object. How far its secondary and collateral purpose of saving fuel may be effected, and whether it can be attained to the full extent of covering the outlay of construction, and the fair remuneration of the patentee, is a subject on which, as an unscientific observer, I can offer no opinion. I can see no reason to presume, that, in this respect, it will be found at all deficient; and, in its application to steam-vessels, I think it probable, that its advantages may be found of the utmost importance. I do not think that science is necessary towards enabling an ordinary observer to form a decided opinion on its merits in the prevention of a nuisance to the neighbourhood of our numerous factory chimneys. Its success in the case of the chimney opposite your experimental furnace is evident and incontrovertible. If it be not worth the while of the owner of a chimney to apply the inventions, I am sure it would be worth the while of his neighbours to subscribe for the purpose. I do not suppose that any one would be rash enough to take my evidence for proof on such a subject; but it is

Liverpool, and at the stationary engine of the Liverpool and Manchester Railway, under the direction of the engineer, Mr. John Dewrance. That at the water-works, with a shaft of 150 feet high, had previously caused an intolerable nuisance; both, however, have since remained unnoticed and forgotten, even by the authorities in Liverpool, apparently from the mere circumstance of the nuisance having been effectually abated, and attention being no longer drawn to it.

With reference to *the place* for the admission of the air, it is here stated, advisedly, and after much experience, that it is *a matter of perfect indifference as to effect, in what part of the furnace or flue it is introduced, provided this all-important condition be attended to, namely, that the mechanical mixture of the air and gas be continuously effected, before the temperature of the carbon of the gas (then in the state of flame,) be reduced below that of ignition.* This temperature, according to Sir Humphry Davy, should not be under 800° Fahr., since, below that, flame cannot be produced or sustained. This, in fact, is the basis of protection in the Miner's Safety Lamp. In practice, the air has been introduced at all *parts of the furnace, and with equally good effect.* Its admission through a plate distributor, at the back of the bridge, and at the door end, effected all that could be desired.

The adoption during the last few years of the *tubular system* in marine boilers, is now to be noticed, inasmuch as it rendered a different arrangement absolutely necessary.

The chief characteristic of the tubular boiler is the *shortness of the distance, or run,* between the furnace and the tubes. The

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possible that parties interested in it may follow my example in judging for themselves by inspection. * * * * I have some doubts whether economy of fuel will weigh as much as I think it ought with the inhabitants of Lancashire. We are, at present, rich and wasteful; but in London, Cornwall, and other districts, this feature of the invention, if duly established on experience, must be of great importance—in steam navigation, perhaps, of still greater. As a coal proprietor, it is not my business to mention it at all; but I do *not* believe, that what tends to benefit the manufacturer will, in the long run, diminish the consumption of coal.

"I am, Sir, yours very truly, F. EGERTON.

"Mr. H. Dircks,
"Messrs. Dircks and Co., 3, Town-hall buildings, Manchester."

result is, the impossibility of effecting the triple duty of generating the gas, mixing it with the air, and completing the combustion within *the few feet*, and the *fraction of a second* of time, which are there available. To obtain the desired effect, the air was then introduced at the *door end* of the furnace; thus, as it were, adding the length of the furnace to the length of the run.

The main object being the introducing the air in a divided state to the gaseous atmosphere of the furnace chamber, the following experiment was made:—The centre bar of a boiler, four feet long, was taken out, and over the vacant space an iron plate was introduced, bent in the form as shewn in Fig. 39.

Here, the upper portion of the bent plate, projecting three inches above the fuel, was punched with five rows of half-inch holes, through which the air issued in 56 streams. Adequate mixture was thus instantly obtained, as in the Argand gas-burner; the appearance as viewed through the sight-holes at the end of the boilers, being even brilliant, and as if *streams of flame*, instead of *streams of air*, had issued from the numerous orifices. It is needless to add, that nowhere could a cooling effect be produced, notwithstanding the great volume of air so introduced.

The sectional view of the furnace, looked at from behind, as in Fig. 40, represents the character and diffusive action of the flame.

Fig. 39.

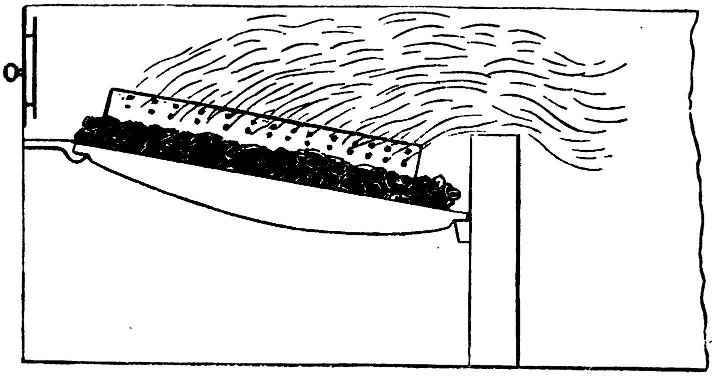
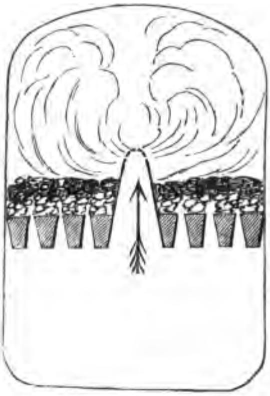


Fig. 40.



This led to the enlarging the door-end of the furnaces sufficiently to admit the required number of apertures and full supply of air; an arrangement which has been for years in successful operation, both in marine and land boilers.

In practice, the great difficulty lay in adapting the plan to marine boilers, the doorways of which are made so contracted, as to render it impossible to introduce the required number of half-inch orifices, as hereafter will be shewn.

Before examining the respective merits of the plans here referred to, it will be advisable to notice one of the causes of derangement, and from which many, though sound in principle, were rendered inefficient in practice.

On looking into the flues of land boilers, through suitably-placed sight-holes, when the furnace is in full action, numerous brilliant sparks may be seen, carried through the flues with great rapidity, to the distance of ten to twenty feet before their luminous character is lost, and they become deposited in the tubes, or flues, or wherever eddies are formed. These sparks consist, chiefly, of particles of sand in a state of fusion. When these do not thus separate from the coal, they fall on the bars, and, combining with the ashes, form clinkers. These particles of sand, flying off at a high temperature, adhere to whatever they touch; and, with the dust, and small particles of cinders or coke, carried onward by the current, fill up the orifices in the air distributor boxes, and, if not removed, prevent the passage of the required quantity of air.

It is now proposed to give instances of such of the modes of constructing furnaces as have been hitherto adopted, and which illustrate any principle, or peculiar mode of action, worthy of notice.

CHAPTER VII.

OF VARIOUS FURNACE ARRANGEMENTS, WITH OBSERVATIONS THEREON.

THE following remarks on the peculiarities of the several plans of furnaces here shewn, are the results of practical observations extended over a series of years, and may here be useful, as indicating what should be avoided, as well as provided, respecting the admission of air.

Fig. 41.

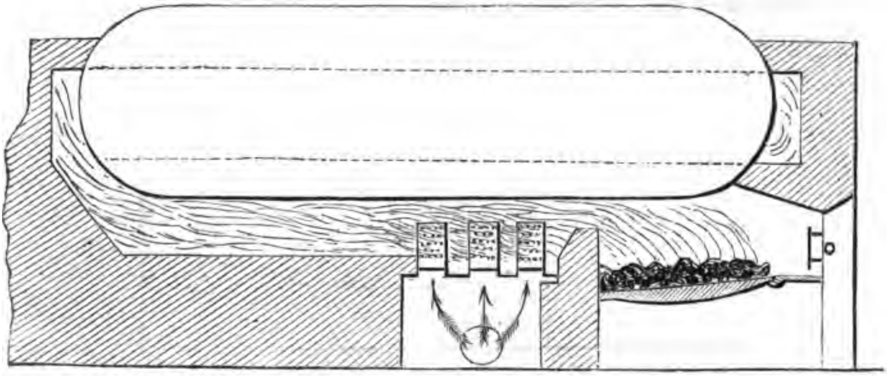


Fig. 41 represents one of the modes first adopted, under the patent for the Argand furnace of 1839; introducing the air in numerous jets. This was applicable to land boilers, where ample space was afforded for the perforated tubes, made of fire clay, or cast iron; and was first adopted at the waterworks in Liverpool. In this application, the inconvenience arising from the sand and other matters in an incandescent state, adhering, and closing the orifices, was considerable. The plan, as already noticed, (from Dr. Ure's Dictionary,) was then substituted, and has continued ever since in active operation at those works.

The following are principally connected with marine boilers:

Fig. 42.

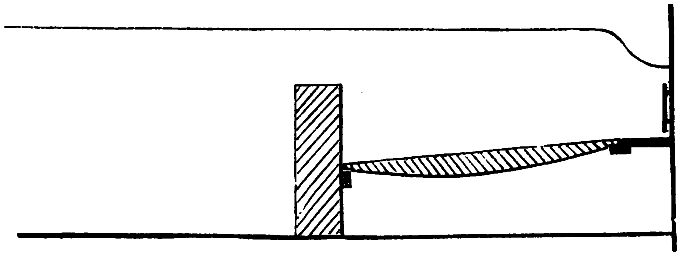


Fig. 42 represents the ordinary marine furnace. No provision whatever is here made for the admission of air, except from the ash-pit, and through the bars, and fuel on them. It is needless to add, that, from the absence of air to the gas, a large volume of smoke must here necessarily be produced.

Fig. 43.

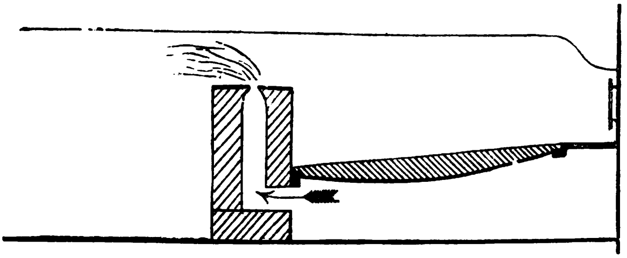


Fig. 43. Parkes' Split Bridge. This plan, patented in 1820, was effective when the consumption of coal, and the generation of gas, were small and uniform; or when the furnace was large, and heavily charged, to last for six or eight hours, with slow combustion. The generation of the gas being uniform, and the demand for air moderate, the supply through the narrow orifice in the bridge was sufficient. This plan has

formed the basis of several *re-inventions;* the Patentees either not being aware of it, or not acknowledging the source of the effect for which they took credit.

Fig. 44.

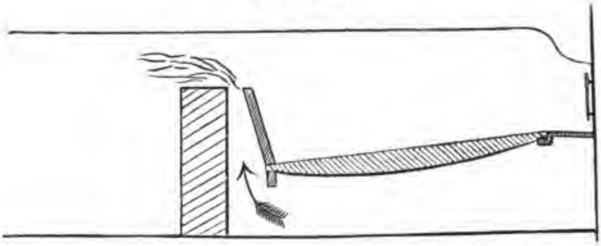


Fig. 44. This adaptation of the Split Bridge in marine boilers was early made, by the then Engineer of the Dublin Steam Company, to avoid the collection of ashes in the lower shelf of the air orifice, and by which the passage of the air was obstructed. The furnaces being charged at short intervals, and the combustion rapid, the supply of air was insufficient. The aperture at the top of the bridge was liable to be choked with ashes and small coals, occasionally thrown over.

Fig. 45.

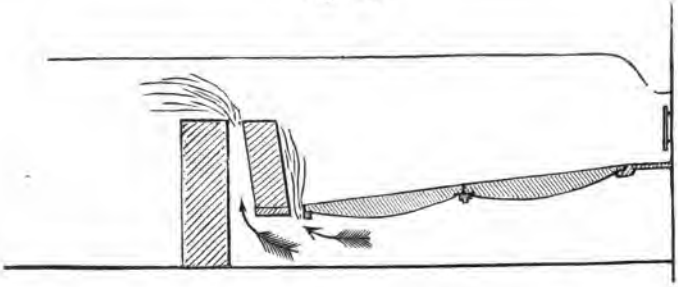


Fig. 45. This change was not found effective. The second opening for the admission of air, at the end of the bars, was quite irregular in its action. It was also found to interfere with the action in the split bridge; the air preferring, at certain states of the fuel, to enter by the open space at the end of

the bars, as the nearest and hottest course, whenever that place was uncovered.

Fig. 46.

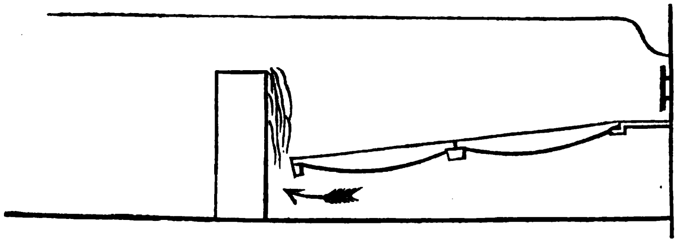


Fig. 46. This was adopted in a steamer of large power, and was intended to remedy the evil as stated in the last figure. The aperture being made larger, the air entered too much in a mass, and produced a cooling effect; and much fuel was also wasted by falling through into the ash-pit. This was subsequently altered to the plan hereafter shewn in Fig. 51; the bars being reduced from 7 feet 6 inches, to 6 feet, and with good effect.

Fig. 47.

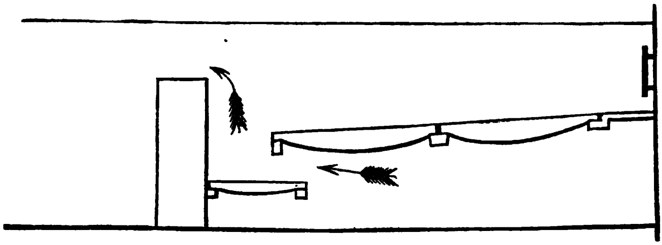


Fig. 47. This arrangement remedied that of the preceding, by saving the fuel thrown to the end; and which, falling on the small supplemental grate, was there consumed. In practice, however, it was less effective as to generating steam, and irregular in its action, and was very destructive of the bars.

Fig. 48.

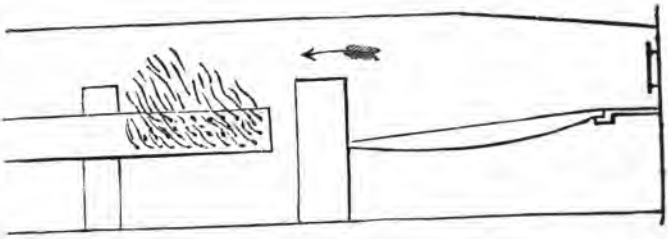


Fig. 48. This plan, adopted in 1840, was one of the first applied to marine boilers, on the principle of the Argand furnace, by which the air was made to enter in ***divided streams***, through the apertures in an eight-inch tube, from behind the boiler. This plan was fully effective so long as the perforations in the tube remained open. The small orifices, each but a quarter of an inch, however, becoming covered, and closed by the sand and ashes, the supply of air was consequently diminished, and the tube became heated and destroyed.

Fig. 49.

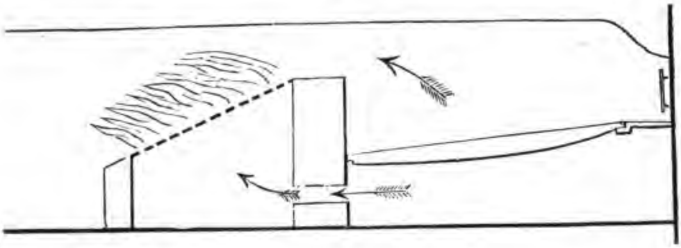


Fig. 49. This plan, adopted in the steamer, the "*Leeds*," was very effective so long as the inclined plate and its numerous orifices remained perfect. As, however, it also became clogged, or covered with coal, thrown over during charging, it warped, and became injured.

Fig. 50.

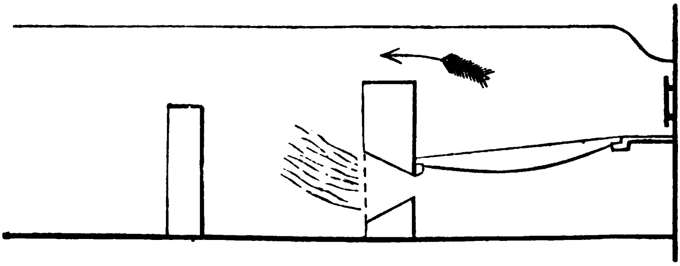


Fig. 50. This alteration was made in the same boiler, to counteract the evil above-mentioned. The bars were shortened from 6 feet to 4 feet 6 inches. The air was here introduced through a plate pierced with half-inch holes. This was quite successful: ignition and combustion were complete; no smoke formed, and the diminished combustion of fuel was considerable. The box, however, set in the bridge, was too small, and therefore liable to become filled by the ashes carried in by the current from the ash-pit; and the stokers neglecting to keep the air-apertures free, there was no dependence on its action.

Fig. 51.

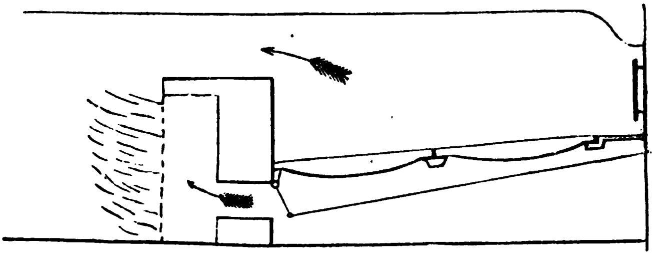


Fig. 51. This arrangement, which remedied the above defects, was adopted in the steamer, the "*Princess,*" and also in the "*Oriental*" and "*Hindostan,*" employed in the Mail service in the Mediterranean. Perfect combustion of the gas was effected, and, consequently, no formation of smoke. The numerous orifices are here removed from the direct action of the heat, or the liability to be choked. The regulating valve, originally placed on the apertures, to regulate the supply, was,

after a little experience, found to be unnecessary, and was removed.* This plan has become, practically, the most effective, and, during the last ten years, has been adopted in numerous marine and land boilers. The cost of the air-box was under forty shillings.

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* The Engineer of these vessels, to which he was appointed successively, after much experience of the value of admitting the air, reported as follows:—

"*Liverpool, August* 26, 1842.

"SIR,

From the experience which I have had of the apparatus on board the mail contract packet, the *Princess*, I found it effected a considerable saving of coals, besides doing away with the smoke, and I, therefore, beg that it will be put into the *Hindostan* before she leaves England.

"I am, Sir, your obedient servant,

"JAMES M'LAREN, Engineer of the Hindostan."

Extract of a Letter from Mr. M'LAREN, dated on board the Steam Ship Hindostan, at Madras, December 20, 1842.

"With regard to the air-boxes, I consider them a great saving to the Company, both in fuel and supporting the bridges; for if we had the common bridges we should have had to rebuild them several times, which might have caused the vessel to be detained some days; but, up to the present time, we have had no occasion to put up a single brick since we left Gibraltar, and the perforated plates are as perfect as when first put into the furnace; and, with regard to smoke, it is seldom or never seen. I am happy to inform you, to the credit of Messrs. Fawcett and Co., that, up to the present time, we have had neither a broken bolt, nor a bad rivet in the boilers, and every thing seems to be in as good order as when we left home. Consumption of coal, twenty-seven cwt. per hour."

Report of the Engineer of the Oriental, plying between England, Gibraltar, Malta, and Alexandria, December 19, 1842.

"The air-distributors answer uncommonly well in this vessel. Consumption, twenty-six cwt. per hour. No smoke whatever."

Fig. 52.

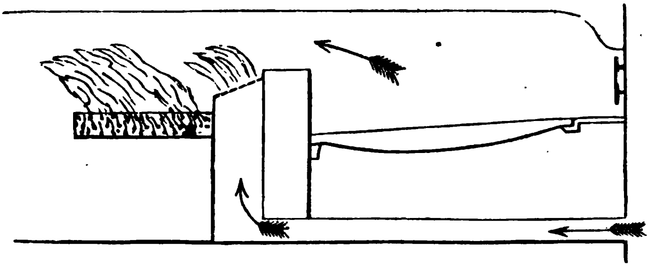

Fig. 52. In this plan, the air was introduced through a tube laid on the bottom of the ash-pit, to avoid the current of dust, and to enable the air to enter in a cooler state. This was found effective as regarded combustion, but, being still exposed to the sand, dust, and heat, as already mentioned, was subsequently altered to that of Fig. 51.

Fig. 53.

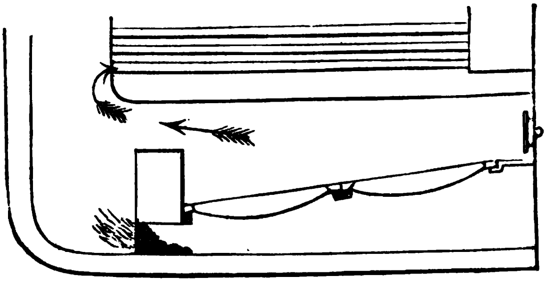

Fig. 53. This was a tubular boiler, and is here shewn as it came from the maker in 1846. It was quite ineffective, giving much smoke, the tubes also being liable to injury by the shortness of the run. The air-box in the bridge was soon filled with dust and ashes, as here shewn. The grate-bar being 6 feet 10 inches long, the flame necessarily reached the tubes, doing much injury to the lower tiers. This was altered, as shewn in Fig. 54.

Fig. 54.

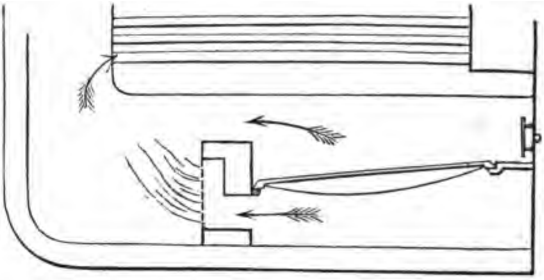

Fig. 54. This is the same boiler, the furnace alteration being attended with considerable advantage. The bars were shortened from 6 feet 10 inches, to 5 feet 3 inches. The defect of the short run, and the limited time for combustion, incident to tubular boilers, was, however, irremediable. The change in the length of the bars alluded to, reduced the consumption of coal considerably; smoke was, to a certain extent, avoided, and the amount of steam increased. In this boiler there were 205 tubes of 2¾-inch area. Engines 190 horse-power.

Fig. 55.

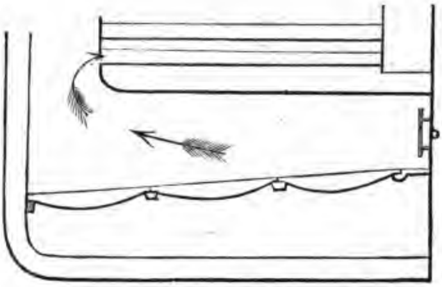

Fig. 55. This was a large steamer of 350 horse-power, with tubular boilers. The plan of furnace here shewn represents it as it came from the maker. Three lengths of bars, 2 feet 8 inches each, *filled the entire space*, leaving no room for the admission of air to the gas. The consequence was, a great

consumption of fuel; a great generation of smoke; and much inconvenience and expense, from the destruction of the tubes and face-plate.

Fig. 56.

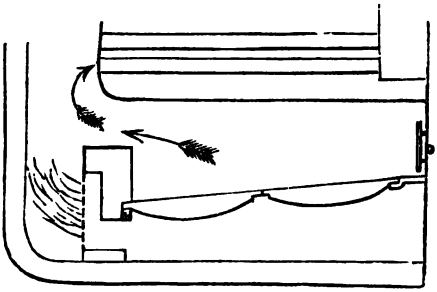

Fig. 56. This is the same boiler. The bars having been shortened, the air-box was introduced into the bridge. Notwithstanding the evils of the short run, the change here made was satisfactory. The importance of keeping the air-passage free from obstruction was exemplified in this case. The air-box was introduced in the *after-boiler*, leaving the *fore-boiler* as shewn in Fig. 55. During the voyage, in which 90 tons 18 cwts. of coal were used in the latter, but 81 tons 15 cwt. were used in the former. The engineer reported, that "when the gases are properly consumed, the best effect is produced; good steam is obtained and less coal used."

Fig. 57.

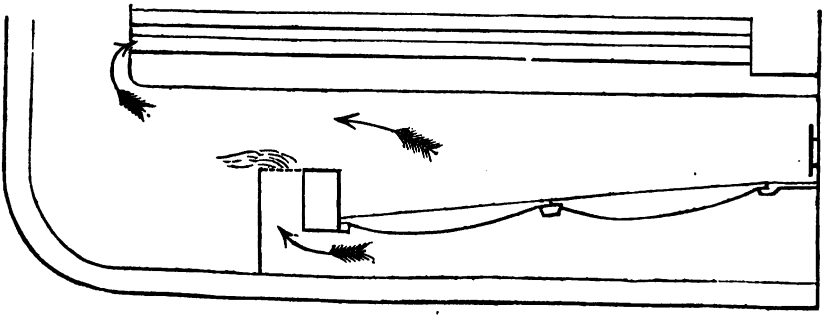

Fig. 57. This boiler also was tubular, 17 feet 2 inches long. Engines 370 horse-power. It is here shewn as it came from the maker. The grate-bars 9 feet; dead plate 9 inches. The area for the admission of the air was quite inadequate to the introduction of the necessary quantity. This boiler was then altered as in Fig. 58.

Fig. 58.

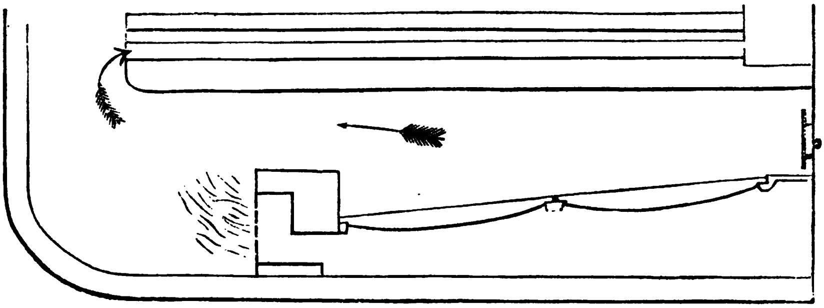

Fig. 58. This is the same large steamer as in last number: the air-box being introduced into the bridge; the result was a considerable diminution in the fuel used; a better command of steam, and freedom from the nuisance of smoke.

Fig. 59.

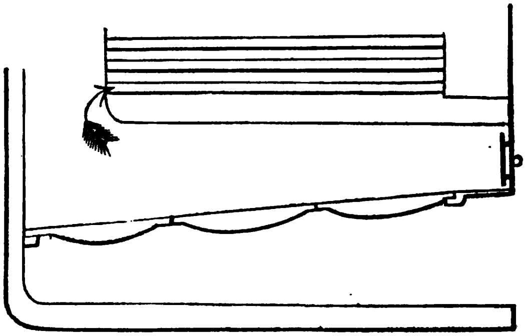

Fig. 59. This tubular boiler is here shewn as it came from the maker; grate-bars 9 feet 3 inches long, with dead-plate 12 inches. No means for admission of the air to the gas. In this

boiler the run to the end of the tubes being so short, the generation of steam depended, almost exclusively, on the large grate-surface from ten furnaces. The consumption of coal was very great, and the smoke very dense. From the shortness of the boiler there was necessarily but little room for improvement It was altered as shewn in next plan.

Fig. 60.

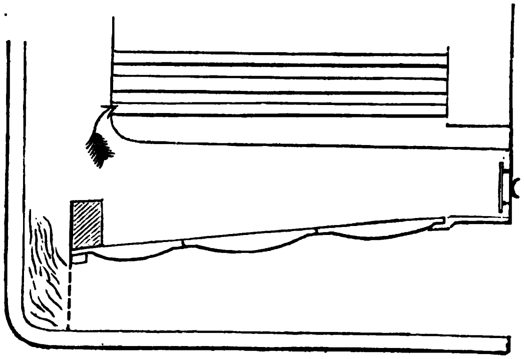

Fig. 60. The same boiler, altered as here described, allowing the air to enter by a *perforated* plate. The inherent defects of the short boiler, and short run, prevented the realizing much advantage in this case.

Fig. 61.

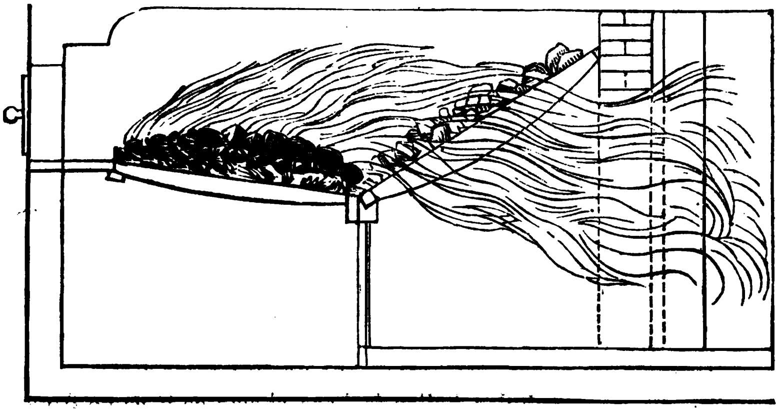

Fig. 61. This plan is here introduced as shewing the practical error of supposing that the gases could be consumed by

causing them to pass *through incandescent fuel.* The effect of this plan is to convert the gas into *carbonic oxide;* and which, from being invisible, created the impression, that the "*smoke was burned.*" It is needless here to dwell on the chemical error of such an assertion. The fallacy of imagining that either gas or smoke, from a furnace, can be consumed by passing "*through, over, or among*" a body of incandescent fuel, as already shewn, prevailed from the days of Watt to the present. Numerous patented plans to the same effect, might here be given, all having the same defect, and equally ineffective.

Fig. 62.

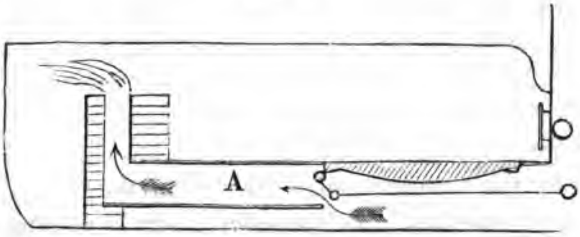

Fig. 62. This was one of the numerous hot-air expedients pressed upon public notice, under the illusion, that by heating the air, "*the smoke would be burned.*" A large hollow fire-bar, A, was placed in the centre, or sides of the furnace, with a regulating door for the admission of the air. The Admiralty having been induced to allow this plan to be adopted in the Steam Packet, the "*Urgent,*" at Woolwich, the result was a total failure, and its consequent removal.* The supposed heating of the air being a mere assertion, made for the purpose of giving an appearance of novelty, having been wholly without effect, the result was, that it reduced the so-called patent invention to that of Parkes' Split Bridge, with all its disadvantages when applied to marine-boilers and large furnaces.

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* The *Urgent,* Captain Emerson, being then engaged in the Mail Service at Liverpool, this steamer came under my notice. For the purpose of testing the effects of this hollow-bar, I had an experiment made to ascertain the extent to which the air might be heated, and found no perceptible increase of heat could be obtained by it.

Fig. 63.

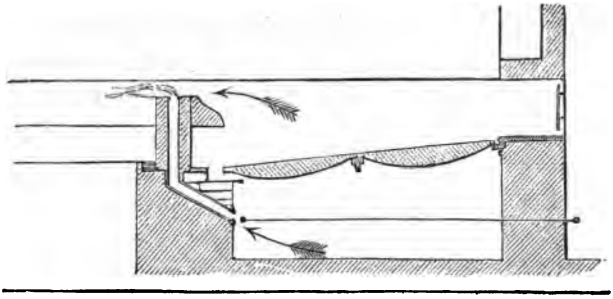

Fig. 63. This was another modification of the Split Bridge plan. Mr. West, in his published Report, on the methods submitted to the Public Meeting at Leeds, in 1842, described this in the following terms: "It consists of a regulating valve, by which air is admitted into a passage through the bridge, (the split bridge of Parkes' expired patent,) for four hours after first firing. By this time the coal is coked, and the valve shut the remainder of the day." It is manifest there is nothing in this plan beyond the split bridge, accompanied with the mode of firing and slow continuous combustion applicable to it.

Fig. 64.

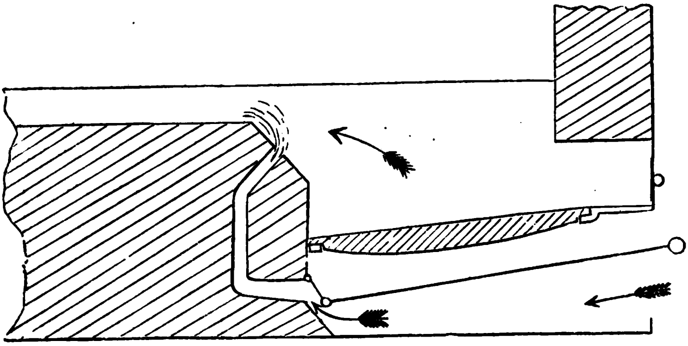

Fig. 64. This is but another modification of the split bridge, though announced as a plan for *heating the air*, by its passage through a body of hot brick-work. This plan, M. Peclet observes, was adopted in France, but abandoned.

Fig. 65.

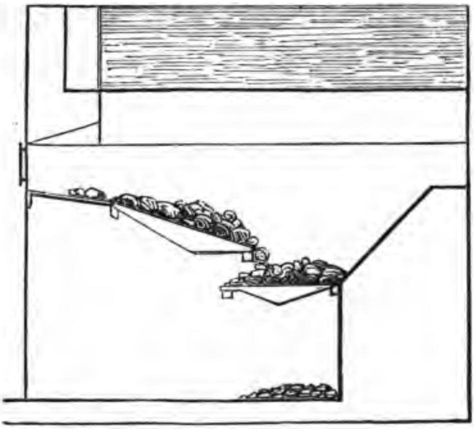

Fig. 65. M. Peclet gives this as one of Chanter's patents, which was also tried and abandoned in France. It will be seen that this is but a modification of the former plans.

Fig. 66.

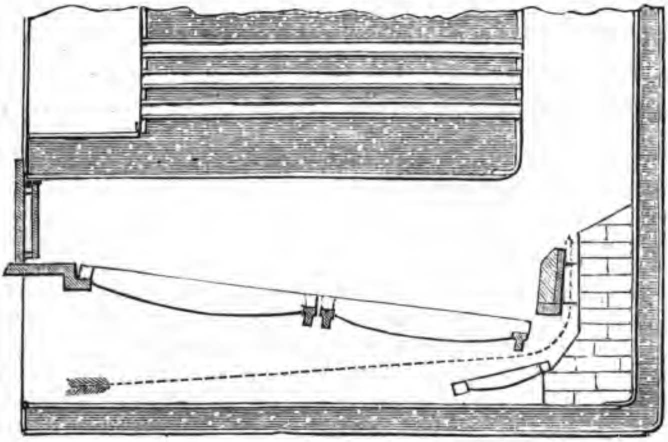

Fig. 66. This is another of the so-called hot-air plans, although it is nothing but the split bridge with a supplemental grate, as adopted by Chanter and others. The Patentee professes to have the air "*intensely heated*," by the handful of scoria, or cinders, which fall on the supplemental grate. This

plan being much pressed on public attention, the Patentee's own inflated description is here given, than which nothing can be more erroneous in a chemical point of view, or more unwarranted in practical effect.*

Fig. 67.

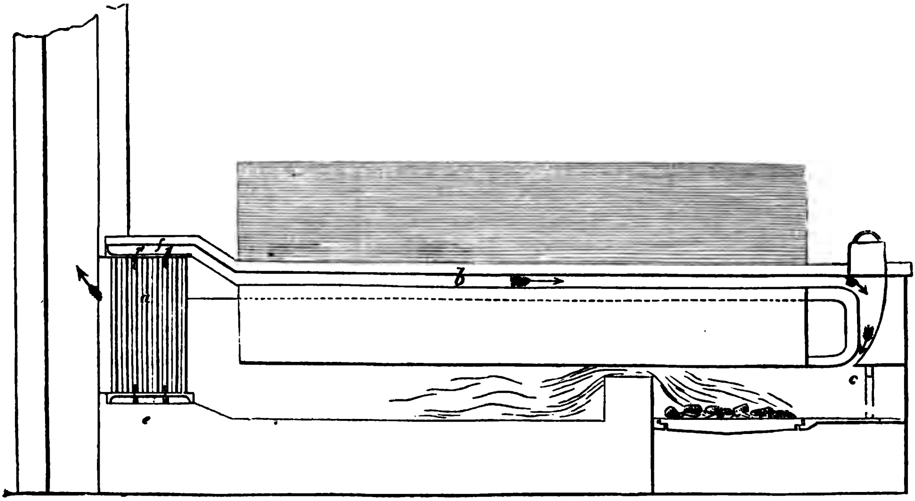

Fig. 67. This is another of the hot-air plans, as given in Mr. West's Summary. The air is here supposed to be heated by passing through the vertical tubes *a*, placed in the flue, and

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* "It will be seen that the invention consists in the combination of two sets of fixed fire-bars, the first of which is chiefly fed by the *scoria* and *cinders voided* from the second or upper set of fire-bars, with a *calorific plate*, the face of which may be protected by a few fire-bricks; by which arrangement, the current of air entering at the lower part of the furnace, *passes through two strata of fire*, and thence between the calorific plate and the bridge, and is thus *so intensely heated as continuously to produce the entire combustion of the gaseous products of the fuel*, and to prevent the ordinary formation of smoke. It is, in effect, a double furnace, confined to the limits of, and economically applicable to, any common description of furnace; has all the advantages of *a hot blast without the cost of any pneumatic apparatus;* is so contrived as uniformly to distribute and keep up the requisite heat in boilers of whatever form; and, whilst most effectually preventing the annoyance of smoke, and the usual deposit of soot in the flues, it causes an average saving of at least 20 per cent. in the quantity of fuel consumed, and also admits the substitution of the cheapest for that of a dearer quality, and of small instead of large coals, as further means of reducing the expense of consumption."

thence through the passage *b*, entering the furnace by a single orifice *c*. It is only necessary to observe, that it would be impossible that one-fourth part of the required quantity of air could there obtain access, unless by so enlarging the orifice as to produce a cooling effect, by its then entering *en masse*. Mr. West states, that the Patentee "claims the right of using hot air for the purpose of consuming smoke, in whatever manner the air may be heated." This claim, it may safely be stated, none will be disposed to dispute.

It seems strange that these numerous advocates for the use of hot air, in ordinary boiler furnaces, have given no information as to the degree of heat which they would give to the air, nor the means by which this heat would be imparted to it. They have made no experiment to test either: neither have they given any grounds for supposing that the air, when heated, would be more effective. [This will be hereafter considered in a separate chapter.]

Fig. 68.

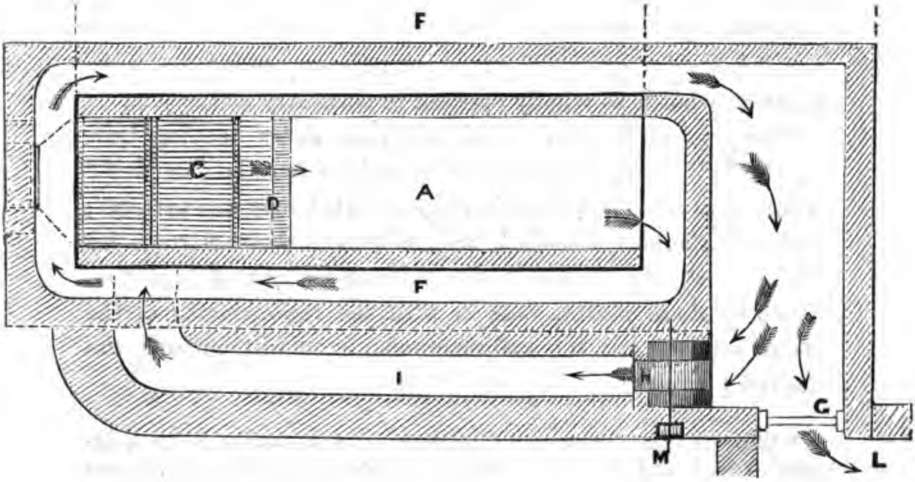
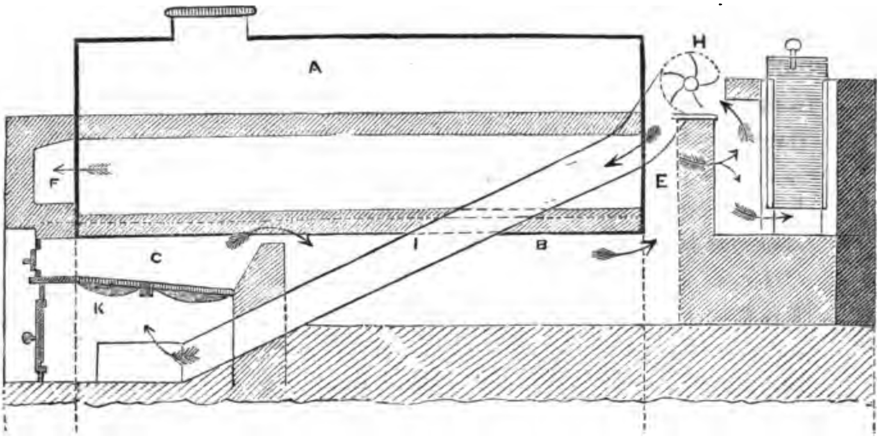


Fig. 69.



Figs. 68 & 69. This plan, as in Fig. 68, with the sectional view, 69, is also taken from Mr. West's Summary, and is here introduced with the view of further pointing to the hot air, and "smoke-burning" fallacy. The following is the description given by Mr. West: "The smoke, after having passed along the flues marked F, is intended to be caught by the fan H, before reaching the damper G, and, along with a sufficient quantity of atmospheric air, is propelled along the return flue I, into the enclosed ash-pit K, where it is again forced through the fire-grate C." It is not necessary to add any comment on what is so wholly opposed to chemistry and nature.

The plans of *Brunton's* revolving grate, *Jukes'* moving bars, or *Stanley's* self-feeding apparatus, need not here be described.* There is in these no pretension beyond what they can perform; each acts the part intended, and, wherever there is room for their introduction, and that the uniform amount of heat produced by these means, falls in with the requirements of the steam engine, and the manufacturer, these will answer the desired purpose.

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* Stanley's apparatus was early applied on board the Dublin Steam Company's vessel, the *Liverpool.* Independent of its inconvenient bulk, it was wholly defective, when applied to large furnaces, requiring the most active firing, and the irregular demand for steam incidental to marine boilers.

We must here observe that these plans are inapplicable to marine furnaces, or where large quantities of steam, and active and irregular firing are required.

The simple operation in these is, the keeping continuously a *thin stratum of fuel on the bars*, and, consequently, an abundant supply, and even an excess of air, through it, to the gases generated in small quantities over every part of the fuel. Neither must we be led to suppose, that they effect a more economical use of the fuel.

In an an inquiry on the subject at the Society of Arts, much stress was laid on the annual saving by the use of the moving bars, at a large establishment in London. It appeared, however, that the saving arose, not from any more economic use of the fuel, or the generation of more heat, or by a more perfect combustion, but merely from the circumstance, that the mode of feeding the furnace, and keeping continuously a thin stratum of fuel on the grate, enabled the proprietor to use an inferior description of coal.

In the case of boilers already constructed, it may be asked how they should be altered so as to admit the required supply of air. In *land boilers*, where the furnace doors are set in brick, they may easily be enlarged, and at a small cost, to allow space for the requisite number of orifices, the aggregate area of which should average five to six square inches for each square foot of grate-bar furnace, according to the description of fuel.

In *marine boilers*, however, the enlargement of the door end is troublesome. Where sufficient space cannot be obtained, it will be advisable, in addition to as many half-inch orifices as can be inserted in the back plate of the close door box, or in the neighbourhood of the door, to introduce the ordinary perforated air-plate, as already shewn in Fig. 51. This was the mode successfully adopted, in the present year, in the mail steam packet, the *Llewellyn*. The boilers being new, and the maker not having allowed space sufficient for door-frame plates of the required size, the deficiency was supplied through the ordinary perforated box in the bridge.

The boilers previously in this vessel were remarkable for the continuous volume of dense smoke: the new boiler, independently of the absence of smoke, supplies more steam with a less consumption of coal. The contrast between the two modes of constructing furnaces, is well exemplified in the following extract from the report of Mr. Joseph Clarke, the Engineer of the Dublin Company, to whom this vessel belongs.*

Fig. 70.

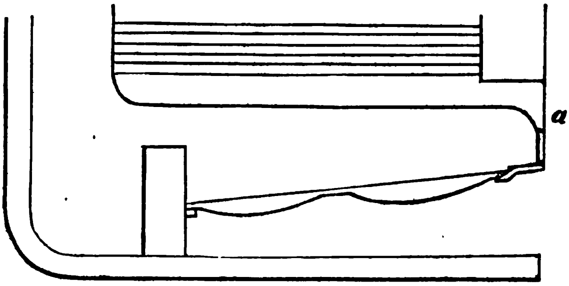
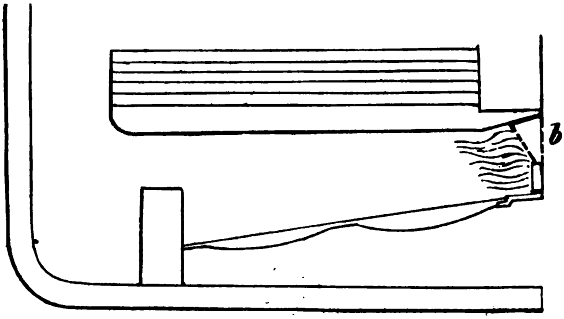


Fig. 71.



In illustration of the alteration which should be made in marine boilers, Fig. 70 represents the usual mode of contracting the door end to the mere size of the door frame, as at *a*. Fig. 71 represents the mode of enlarging the opening, both at the sides and above the doorway at *b*, to allow of the introduction of a sufficient number of half-inch apertures, as shewn in Fig. 72. It is here worthy of note, that as the ordinary mode of constructing the door end of marine boilers is difficult and expensive, as shewn in Fig. 70, the mode shewn in Fig. 71 is so much more simple as to cover all the outlay for the air boxes shewn in the next figures.

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* "The Holyhead mail steam packet, *Llewellyn*, having now been at work three months with new boilers, I have to transmit you the result of their performances. This vessel has two boilers; one before, and the other abaft the engines. Their construction are precisely the same; each having six furnaces. Both have all their furnace fittings exactly the same. In order to put the smoke-prevention principle in contrast with the ordinary mode, the *fore boiler* was allowed to remain as it came from the maker, while the *after*

Fig. 72.

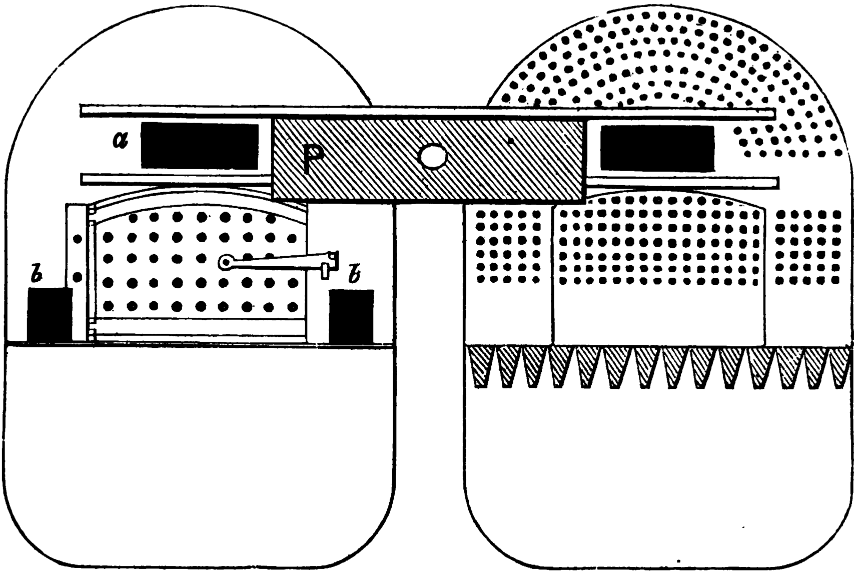

Fig. 72 represents one of the modes adopted where the boiler

one had the door frames of each of the furnaces (which are made with box mouth pieces) perforated with 149 holes, each $\frac{7}{16}$ inch diameter, to admit the air. These not being sufficient, the perforated plate behind the bridge was added, in which there were 321 holes—in all, 470 holes; the gross area of which is equal to about 5 square inches for each square foot of fire grate. The result is, that the fore boiler gives out a continuous volume of dense smoke, and the after one none whatever. It is quite remarkable to see the steam blowing off from both boilers, and smoke only from one. I know nothing that could be more demonstrative of a principle than the contrast between the two boilers in this vessel. It attracted the attention of the passengers, and I resolved, therefore, on leaving the two sets of furnaces as they are for some time longer, to afford the public the opportunity of seeing that smoke prevention is practicable. When the vessel can be spared, it is my intention to make the furnaces of both boilers alike."

had been *originally constructed to admit the required number of orifices.* This has been in successful operation for some years, and without requiring any repairs. In this plan it will be seen that air boxes are introduced at the sides and above the doors. The air entering to the upper box at *a*, and to the side boxes at *b b*. (The left representing an outside, and the right an inside view of the orifices.) In the centre is a sliding plate P, by which, alternately, the right or left hand upper orifices may be closed, when either furnaces are about to be charged.

As much stress has been laid on the value of having skilful firemen, it is important to shew in what their real duties consist. The annexed figures will explain the difference in effect between the right and the wrong mode of charging a furnace.

Fig. 73.

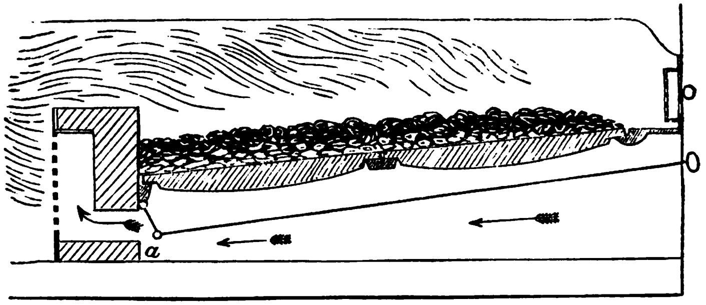

Fig. 73 represents the proper mode of keeping a uniform depth of coal on the grate bars;—the result of which will be, a uniform generation of gas throughout the charge, and a uniform temperature in the flues.

Fig. 73*a*.

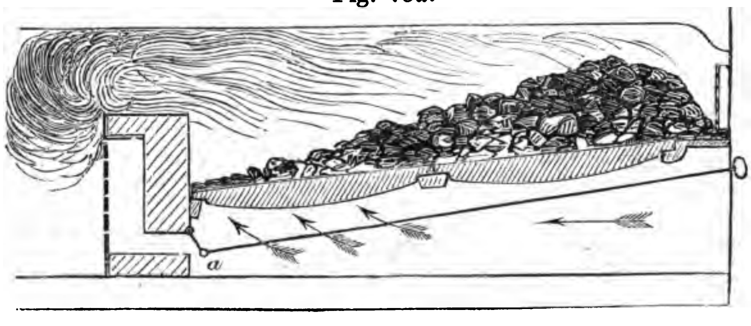

Fig. 73*a* represents the ordinary mode of feeding marine furnaces: charging the *front half* as high, and as near the door, as possible, leaving the bridge end comparatively bare. The result necessarily is, that more air obtains access through the uncovered bars than could be required; thus defeating all efforts at introducing the proper quantity in the proper manner.

One important advantage arising from the control of the quantity of air is, that it enables the engineer to shorten the length of the grate by bricking over the after end of the bars, seeing that an unnecessary length merely gives the means of letting an improper supply of air pass in through the uncovered bars.

The facility with which the stoker is enabled to counteract the best arrangements, naturally suggests the advantage of *mechanical feeders.* Here is a direction in which mechanical skill may usefully be employed:—the basis of success, however, should be the sustaining at all times the uniform and sufficient depth of fuel on the bars.

Although the combustion of the gases in locomotive boilers does not come within the scope of these remarks, the peculiarities of the boiler, as shewn in Fig. 74, are so illustrative of the principle of admitting the air through numerous orifices, that it here merits attention.

Fig. 74.

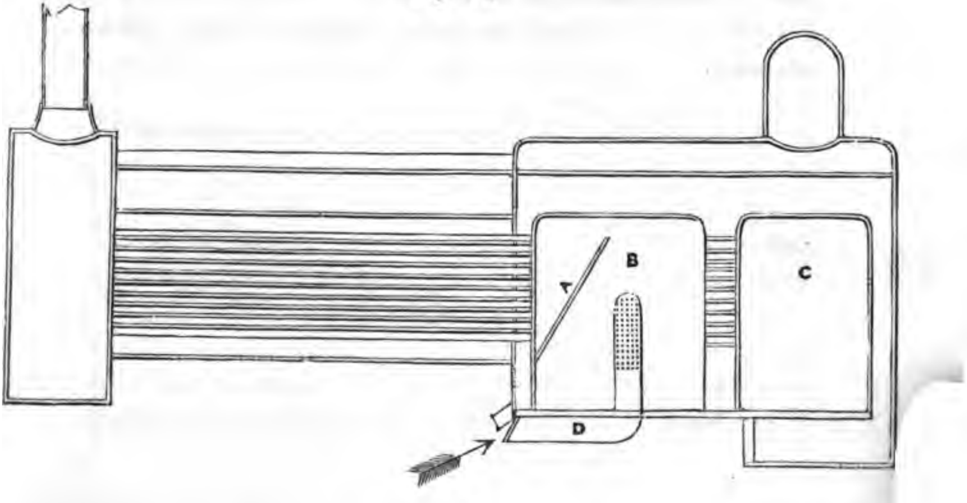

Fig. 74. This plan of boiler is the invention of Mr. Dewrance, when Engineer to the Liverpool and Manchester Railway Company, and was adopted in their locomotive, the *Condor*. By this arrangement he was enabled to use *coal* instead of coke, and with entire success. It will here be seen that the air enters from a separate passage to a number of vertical perforated tubes, from which it passes to the gas, in a large mixing or combustion chamber, through numerous small orifices. The result is, immediate diffusion and combustion. The deflecting plate, to a certain extent, counteracts the short run, or distance to the tubes.*

In concluding these observations on the various modes of introducing air to the furnaces, it is only necessary to add, that by attention to what is here stated, manufacturers may become independent of "smoke-burning" patents. All they have to do is, to imitate, as near as possible, the principle of the common Argand gas burner. Let them introduce *the air by numerous small orifices to the gas, in the furnace, as the gas is introduced by small orifices to the air in the lamp.* They want no aid from any patentee. Let them begin by having as many half, or even three-quarter, inch orifices, with inch spaces, drilled in the door and door frame, as possible. If the furnace be large, and the door-plate frame is not sufficient for the introduction of the required number of holes, let them introduce the perforated plate in the bridge, as shewn in Fig. 51, and as described by Dr. Ure in his Dictionary of Arts, last Edition, title, "Smoke Nuisance."

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* A, deflecting plate; B, combustion chamber; C, common coal fire; D, cold air passage.

CHAPTER VIII.

ON THE PROVIDING ADEQUATE INTERNAL SURFACE FOR TRANSMITTING THE HEAT TO THE WATER FOR EVAPORATION.

On this head, marine boiler-makers content themselves with calculating the gross internal superficies; and having provided a given number of square yards, of so called *heating surface*, they consider they have done all that is necessary for providing an *adequate supply of steam.*

This might be sufficient, were there any ground for assuming that a square yard of surface, possessed a given evaporative power. Nothing, however, can be more vague, and, practically, more deceptive, than the supposed heat-producing value of a square foot of grate-bar; or the heat-transmitting power of a square yard of internal surface; both being, momentarily, subject to numerous influences connected with time, temperature, current, and position; and the ever varying admission and action of the air.

At present, practice and theory are utterly at variance on this matter. Take, for instance, the separate surfaces of the fire-box and tubes of a locomotive boiler; a square-yard of the latter having but one-third the evaporative effect of one in the former. Indeed, many instances might be given, of the evaporative effect being increased, by the removal of many entire tiers of tubes, and even by a large diminution of the gross area of surface.

As to general efficiency, the *flue system* is capable of supplying all that can be required, while it is free from the anomalies incidental to the multi-tubular plan. When larger quantities of steam are required for larger engines, this can be best obtained, not by additional tiers of tubes, but by extending the areas and length of run; thus increasing the number of units of *time, distance,* and *surface,* along which the heat-transmitting influence may be exerted. It is a mistake then to suppose, that the mere providing a large *aggregate of surface,* can compensate for deficiency in the *run,* or the want of sufficient *time.* The heated products, will not, and cannot be forced instantaneously to spread themselves over the *aggregate* of surface that may have been provided.

Among the influences which affect the transmitting power of any given surface, none are greater than the *velocity of the current* through the flues. The products of combustion being at a high temperature, are found to take the *nearest, hottest,* or *shortest* course to the funnel, — *entering the lowest tier of tubes first,* — regardless of whatever surface may have been *elsewhere provided;* in fact, passing through but a limited number of their ranges.

It is an error then to suppose, that by presenting *additional series of tubes,* we can compel the gaseous products, hurrying to the funnel, to occupy them, or go out of their way, to take the course we may please to dictate. With equal consistency might we expect that the rapid course of a river stream would be eased by providing additional surface in some adjoining district; but through which the direction of the current would not lead it. *Lineal distance,* or length of run, along which the heated products pass, is the most important, though the most neglected, element in the calculation of surface.

Among the modes of providing adequate internal surface, none have led to greater errors than the endeavour to make smaller and shorter boilers do the duty of larger ones, and supply steam for larger engines, by the adoption of the multitubular system. The result has been, a less perfect combustion; a larger development of opaque smoke; a greater waste of fuel and heat; and a more dangerous application of it. Where increased power was employed, and a larger supply of steam was required, instead of providing a corresponding enlargment of the boilers, engineers have inconsiderately adopted the *locomotive tubular* principle, apparently for no other reason than that it was *smaller,* but without considering the irreconcileable differences in the two services, and the peculiarities incident to each. Not finding that the enlarged aggregate *internal tubular surface* produced the expected increased quantity of steam, they had recourse to the other alterative—the *enlarging the areas of the furnaces, and increasing their number*—the generation of the steam almost exclusively depending on the *plate surface in connection with them.*

The adoption of the tubular system in marine boilers, was also accompanied by this anomalous proceeding; that while the areas of the furnaces and grate-bars were *enlarged,* more fuel necessarily consumed, and more gas generated, nevertheless, the *time and distance* allowed for the transmission and absorption of the increased quantity of heat generated, were *both actually diminished.*

It is clear, therefore, that in these arrangements all the requirements of nature were disregarded. All merged in the one consideration—the diminishing the size of the boiler, increasing the area of the furnaces, and providing a *larger aggregate internal surface* by the tubular system. The question, indeed, seems never to have been raised, whether that additional surface was ever, or to what extent, brought into action.*

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* Under the head of "Want of general principles in the construction of marine boilers," Dr. Lardner justly observes, "There cannot be a more striking proof of the ignorance of general principles which prevails respecting this branch of steam engineering, than the endless variety of forms and proportions which are adopted in the boilers and furnaces which are constructed, not only by different engineers, but by the same engineers, for steamers of like power and capacity, and even for the same steamer at different times." He then adds, "The original boilers of the *Great Western* built for the New York and Bristol voyage, was of *the flue sort;* these were subsequently taken out and replaced by *tubular* boilers; the dimensions and relative proportions of these two sets of boilers were as follows."—He then gives in detail all the particulars, the leading points of which are as follows:—observing, that "this vessel was less efficient with the second set of boilers."

	Original Boiler.	Second Boiler.
Nominal horse power . .	400	400
Total heating surface . .	3840 square feet.	7150 square feet.

As to the importance of *time and distance*, in connexion with surface, it is only necessary to point to the *length of the flame*, in ordinary boilers—that being an unmistakeable evidence of the *duration of the process* of the combustion of *the carbon;* and which process cannot be interfered with, unless by the loss of that heat which would have attended its completion.

The following experiment will give a sufficiently correct view of the duration of this process, and what ought to be the distance[*] and surface allowed to take up the heat. In this case, the boiler was 15 feet long; the furnace 4 feet 3 inches, with a returning upper flue. The air was properly supplied, the combustion perfect, and no smoke generated.

Time.	Length of flame after *a fresh charge.*
After 5 minutes,	10 feet from the bridge.
„ 10 „	12 „ „
„ 15 „	15 „ „
„ 20 „	18 „ „
„ 25 „	22 „ „
„ 30 „	22 „ „
„ 35 „	18 „ „
„ 40 „	14 „ „

During the last 10 minutes the flame ceased to be that of *coal-gas* (carburetted hydrogen), and had become that of *coke-gas* (carbonic oxide). There could be no mistake in this, the colour and character of the two gases being so different and well defined, as may be clearly observed through the sight holes, placed opposite the furnace.

Had this been a tubular boiler, the run from the furnace to the funnel, instead of being 36 feet, would not have been one-tenth of that distance. The flame, which at one time we see extended to 22 feet, must necessarily have been violently cut short and extinguished; or its heat expended in the chimney. The atoms of carbon would have been converted from the in-

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This is sufficient to prove the fallacy of a large aggregate of heating surface. The first boiler, which was a good steam producer, had 9 square feet per horse-power; the second, the tubular one, about 17 feet — nearly double — yet the generation of steam was inferior in the latter.

candescent state of flame into the black element of smoke; heat would have been lost to the boiler, and the tubes would have become lined with the non-conductor soot.

If the flame passing from a furnace be *clear*, the combustion may be considered as complete, and the full measure of heat obtained from the fuel — the pyrometer indicating the available amount of that heat. Mr. Dewrance states, respecting a land-boiler, properly fitted with the perforated air distributor: — "We have a clear flame along the flues to the distance of 30 feet from the fire, and the flues at that distance are quite hot; previously to the admission of air in the proper manner, this part was quite cold." Now, had this been one of the usual short marine tubular boilers, what would have been done with this flame, or the heated products passing from it? and of what avail would have been the surface of the series of small tubes? It is manifest, then, that this question, as to the length of the flame, and the demand for time and distance, was not sufficiently considered, when the tubular system was introduced into marine boilers, *using coal*, in imitation of the locomotive *using coke*.

Mr. Atherton considers, that in tubular boilers, "the gases are so minutely sub-divided in their passage through the tubes, that whatever amount of heat may have been generated, is rapidly communicated to the water." Now this fact of *sub-division* produced by the forced entrance into small tubes, becomes the very source of loss of that temperature which is essential to the generation and continuance of flame. Whatever heat had been generated by the flame, on its arriving at the tubes, and on being forced into their narrow orifices, instead of being available, would be virtually sacrificed, and but little, if any, left to be "sub-divided in its passage;" since, as has been well ascertained, the temperature within the tubes, where the black smoke prevails, is frequently not sufficient even to injure paper or shavings. In truth it is only when the fires are clear, and the fuel incandescent, that there is sufficient heat in the tubes to generate any steam. This "minute sub-dividing" of the heat, then, is only correct as regards the *locomotive*, *where* *coke alone is used,*—where there is no carburetted hydrogen gas,—and no fuliginous flame is generated.

Again, in addition to the heat obtained by direct radiation from the flame, we have to consider that large quantity which would have been given out by the gases, *if their combustion had been completed.* It may here be observed, that it is the obtaining the service of the heated products by an adequate run of flue, with sufficient time and surface, that characterizes the *Cornish boilers.* In these the main feature consists in generating, by *slow combustion,* no more heat than can be taken up, and transmitted to the water. In this respect, then, it is the direct reverse of the tubular system. In the former, there is slow combustion,—a continuous small development of combustible gas,—a long run,—abundant absorbing surface,—a moderate rate of current,—free access of the water to the flues,—and sufficient time to enable the surface plate to do its duty;—added to the adoption of every possible means of preventing the loss of heat, externally, by clothing the outside of the boiler.

In the marine *tubular boiler,* on the other hand, every thing is the reverse. There is the most rapid combustion,—the largest and most irregular development of gas,—a rapid current,—a short run,—a restricted and imperfect circulation of the water,—and a total *inadequacy of time* for the transmitting and absorbing processes, with a great waste of heat by radiation from the boiler.

Another serious evil of this tubular system, and its short run, which carries the heat away so rapidly, is, *the over-heated state of the funnel and steam chest;* and the consequent danger to the part of the vessel in their immediate contiguity.

The cause of such heat in a situation where it can be of no avail for the purposes of evaporation, has not been sufficiently inquired into. To this circumstance, without, doubt was attributable the destruction by fire of the *Amazon* steam ship. The excessive heat of the lower part of the funnel, the take-up and steam chest,—*both of which were in that vessel under deck,*—created a source of danger which does not exist in vessels where both are *above* the main deck.

With reference to the availability of the tubular surface, even the *horizontal position* of the tubes, and their being ranged in tiers *above each other*, is peculiarly unfavorable. The lower tiers presenting the nearest opening for the escape of the heated gaseous products, are first occupied, and at an accelerated rate of progress.

Mr. Atherton has given this subject his attention, yet he has overlooked the chemical influences which sub-division, by means of tubes, exercises on flame. "The flue system," he observes, "is more favorable to the effecting a perfect combustion of the fuel, than the tubular." This is true; but when he adds, that "the tubular system is more favorable to the due transmission of the heat to the water in the boiler," this is not borne out in practice.

Mr. Atherton, however, has given the most convincing proof of the waste and danger of the tubular system. Speaking of the combustible gases evolved from coal, he observes, that "after having passed through the tubes, the proceeds from all the different furnaces become collected in the up-take and funnel; and being there combined and mixed together, *they burst into useless combustion, frequently making the funnel red hot.*" This is unquestionably true, but it only shews that *the combustible gases must have passed through the tubes unconsumed;* and having, in the smoke box, encountered the air (which should have been supplied earlier), "*then burst into useless combustion.*"

But there is a more important reason for the large "sectional area" in the flues which has not been referred to by writers on the subject, viz., that it is absolutely essential, chemically, to the completion of the process of combustion and *the disposing of the products, of which water is so large a one*, as will be shewn hereafter.

In calculating the effective surface, then, it should be taken with reference to the *length of the road*, so to speak, along which the heated products have to travel in their hurried course, rather than to the *breadth*, or *enlarged areas*, which may be, *laterally*, or accidentally provided, but which are practically not used or available.

CHAPTER IX.

OF FLAME, AND THE TEMPERATURE REQUIRED FOR ITS PRODUCTION AND CONTINUANCE, AND ITS MANAGEMENT IN THE FURNACES AND FLUES.

THE consideration of the nature of flame would appear to have belonged to the first part of this Treatise, where the relation which bodies have, *chemically*, to each other, are examined; rather than to that of their *practical application* in the furnace. In the present case, however, they are so intimately connected, that it seemed impossible to do justice, either to chemistry or practice, by treating the one apart from the other. This will be the more evident as we proceed.

Treating of the temperature required for the combustion of carburetted hydrogen gas, is virtually treating of *flame*, which is the first product of that combustion. On this subject we may take Sir Humphry Davy as our guide, as he made it an object of such special inquiry. In his "Researches on Flame," he observes, "I shall proceed to describe the origin and progress of those investigations which led me to the discovery of the principles by which flame may be arrested and regulated. I first began with a *minute chemical examination of the substances with which I had to deal.*" So far from adopting the same rational course, though dealing with the same subject, writers of the present day begin with calculations respecting the *proportions of the vessels*, into which the several substances are to be introduced, while they omit the "*chemical examination of the substances*" themselves.

Having, after numerous trials, ascertained the *volume of air* required for the combustion of the gas, he next treats of the *temperature* required for the production of flame; that is, for igniting the given mixture of gas and air, which he calls an "*explosive mixture.*" "This mixture," he observes, "was not exploded, or fired, by red hot charcoal, or red hot iron; it required the iron to be *white hot* for its inflammation."

That this heat is required for the ignition of the *first mixed group of gas and air* to which it is applied, we have daily proof, when, to light the gas in our apartments, we apply the heat of a *separate flame* before ignition takes place. This is confirmatory of the high temperature described by Sir H. Davy, since, as he observes, "the temperature of *white hot metal is far below that of flame.*" Now, in lighting the gas from our burners, we are apt to overlook the all important fact, that it is not *the gas* which we ignite, but *the mixture of gas and air.* On the taper being applied, explosion, or sudden ignition, then takes place of *just so much, or so many groups, of the gas and air, as have obtained the necessary atomic contact, and no more.*

That a high temperature must, unintermittingly, be maintained in the chamber part of the furnace, will at once be understood, when we consider, that flame, continuous though it appears to be, is but a rapid succession of electric explosions of atoms, or groups of atoms, of one of the constituents of the gas—the hydrogen with oxygen; and as rapidly as their respective atoms obtain access and contact with each other; the second constituent—the carbon—taking no part in such explosions. Whatever, therefore, interrupts this succession; (that is, allows the explosion of one group to be terminated before another is ready, and within the range of its required temperature), virtually causes the flame to cease; in ordinary language, *puts it out.*

Again, if by any *cooling agency* we reduce the temperature below that of accension, or kindling, the effect is the same: *the succession is broken,* and the continuousness of the flame ceases; as when we blow strongly on the flame of a candle, by which we so cool down the atoms of gas that they become *too cold for ignition,* and pass away in a grey-coloured vapour; but which, by contact with a lighted taper, may again be ignited, and the succession restored.

Thus we see there are two modes by which flame may be interrupted, that is extinguished; both of which are momentarily in operation in our furnaces. 1st. By the want of successive mixture or groupings of air and gas. 2nd. When the gas is reduced in temperature by cooling agencies, as will hereafter be shewn.

Luminosity is neither an element nor an incident of flame. It is merely the result of the presence of some other and *solid matter*—the degree of luminosity being in proportion to the quantity and temperature of such solid matter. In the combustion of coal gas, flame is caused by the union of the *hydrogen* with atmospheric oxygen, the heat produced being intense, raising the carbon, if present, to the state of incandescence, and producing the effect of luminosity. Here we may admire the wonderful adaptation of nature to human wants. Without the hydrogen, there would be no heat; and without the carbon, there would be no light. The luminosity of the incandescent carbon, then, is the mere result of that high temperature which is essential to its own subsequent combustion, or chemical union, with oxygen.

Let this fact, then, be borne in mind, as it indicates the cardinal point of the whole process in our *furnaces*, namely, that it is not *the gas*, but the *mixture*, the *compound of gas and air*, that is ignited, and which produces the flame, with its heat and luminosity.

This necessary condition of *mixture* clearly exposes the error of supposing that the gas may be ignited or consumed by being made to pass over, *or in connection with the red hot fuel.* Sir H. Davy has shewn that no degree of heat will consume gas—combustion being, not the heating the gas, but the *chemical union* of its constituents with the oxygen—*mixing* being but the preliminary operation of bringing those constituents and the supporter of combustion into atomic contact, or within the sphere of chemical or electric action.

The two essentials of combustion being laid down by Sir H. Davy, viz.—*temperature and contact,* he then considers the management or treatment of the flame, and the means by which it may be effected or extinguished. He states, that on mixing one part of *carbonic acid* with seven parts of *the mixture of gas and air;* or one part of nitrogen with six parts of the mixture, their *powers of explosion were destroyed,*—that is, *ignition was prevented.* Here is a fact never to be lost sight of, inasmuch as its application is called for in every stage of the process in our furnaces and flues.

Again he observes: "If combustible matter requires a high temperature for its combustion, it will be *easily extinguished* by rarefaction or by *cooling agencies,* whether of solid substances, or of incombustible gases." This is highly instructive; yet, the supplying these very means for extinguishing the flame are the characteristics of the tubular system, namely—"destroying the high temperature by *rarefaction, cooling agencies,* and *mixing with incombustible gases.*"

On examination of what passes in furnaces *using coal,* we see the direct connexion between its effect, and what Sir H. Davy so clearly points out as the means of *extinguishing the flame.* On looking into a *flue boiler* from the back end, a body of flame will be seen flashing along from the bridge, and if air be properly introduced, extending a distance of 20 to 30 feet. This is the appearance which has to be sustained *until the process of combustion be completed,* if we would have the full measure of heat developed.

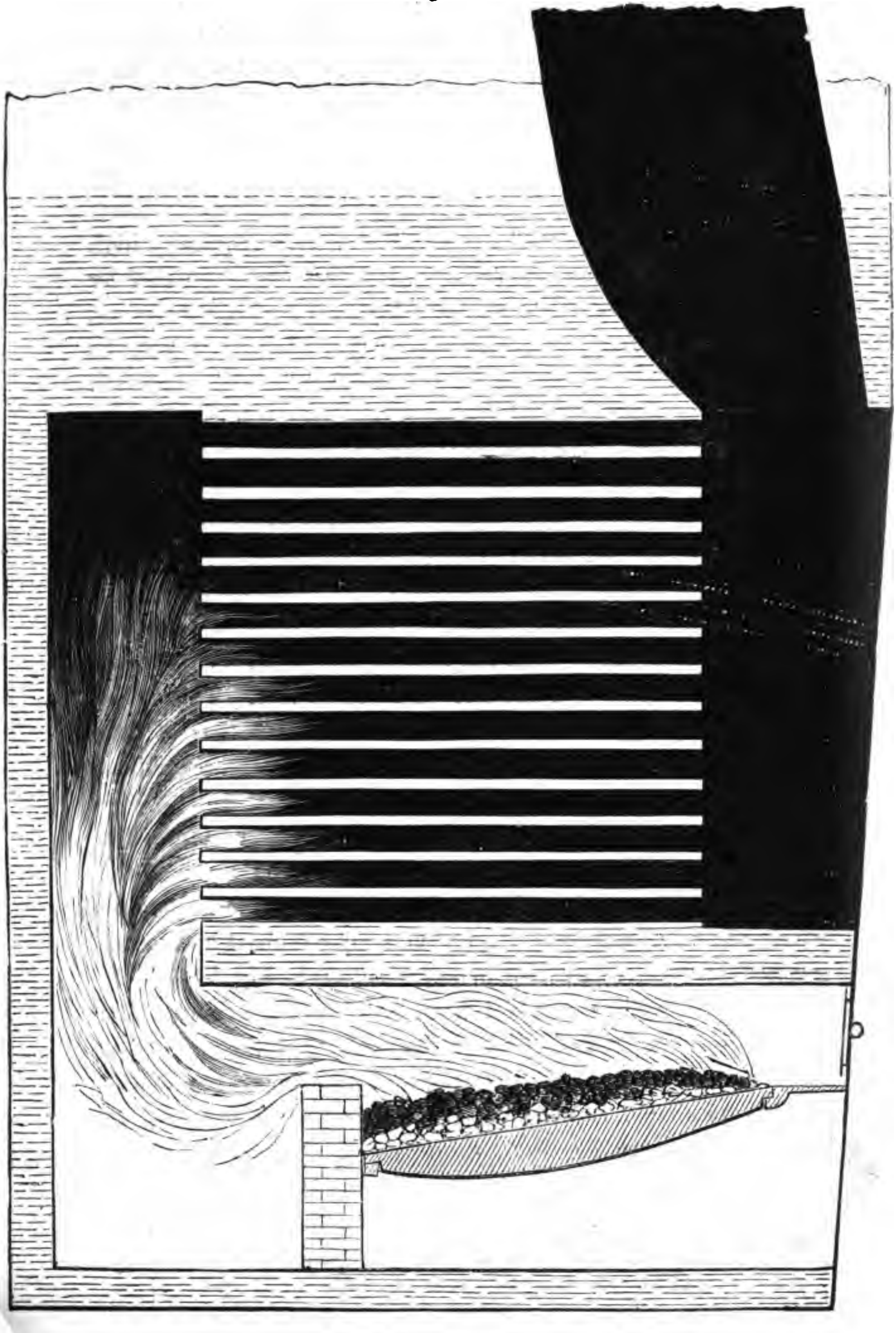
On the other hand, looking into a *tubular* boiler, across the smoke-box, the light of the flame may be seen through the tubes; but, on entering their orifices, or at a short distance within them, it will appear to be suddenly cut short and extinguished, and converted into smoke, as shewn in Fig. 75.

The distance, then, to which flame will penetrate tubes, *before being extinguished,* will depend on the rapidity of the current,—the size of the orifices,—and the quantity and character of the gaseous products, *entering in company and in contact with it.* These products are—

From the coke . . carbonic acid and nitrogen.
From the gas . . carbonic acid, nitrogen, and steam.

Here we have the very incombustible gases referred to by

Fig. 75.



Sir H. Davy,—not even in small, but in very large quantities,—forced into the most intimate possible mixture with the flame. The result necessarily must be, the reduction of its temperature, and consequent extinguishment.

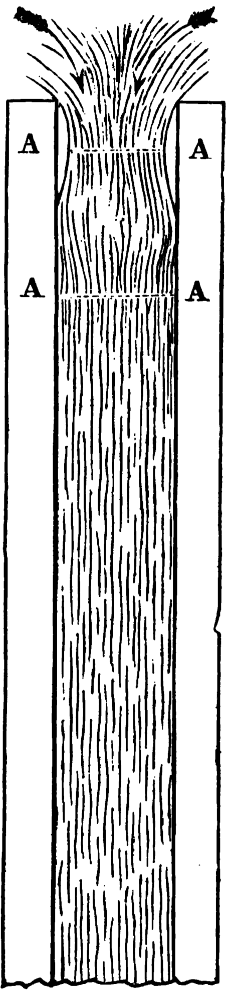
Impressed with the importance of the connexion between temperature and ignition, Sir H. Davy dwells on the fact, and repeats, that "flame, whether produced from the combustion of *large or small quantities* of explosive mixture (gas and air), may always be extinguished or destroyed by *cooling agencies;* and, *in proportion to the heat required to carry on combustion, so it is the more easily destroyed.*"

Again, he observes:—"In reasoning on these phenomena, it occurred to me that the effect of carbonic acid and nitrogen, and of the surfaces of small tubes, depended on their cooling powers; upon their *lowering the temperature of the exploding mixture* so much, that it was no longer sufficient for its *continuous inflammation.*" It is impossible that words can be more explicit, or more applicable, and cautionary, as to the consequences of bringing these incombustible gases into contact with flame. Yet this mixture, and these cooling agencies, are promoted in the most palpable manner and to the greatest extent, by forcing the flame, *together with these gases,* to enter the hundreds of long narrow metallic tubes, with their small orifices;—thus dividing into numerous films, and destroying the body and intensity of the heat, which should have been preserved; since, as he observes,—"*the heat communicated by flame must depend on its mass.*"

Under the circumstances of an ordinary *flue* boiler, if the flue be of sufficient area, the products of combustion *separate themselves,* as seen in the flame of a candle, and as will hereafter be shewn. So, in the flue, the hottest portion, and the flame itself, will take the upper part, thus avoiding that unnatural mixture with its own incombustible products—carbonic acid, nitrogen, and steam; but which in the tubular system are again forced into contact with the flame from which they had separated themselves.

That the temperature *within the tubes* will be reduced below that required for continuous ignition, may be tested by looking into them through apertures across the smoke-box end, or by introducing shavings or paper fixed to the end of an iron rod. In most cases (unless when the fuel on the bars is clear) the paper may be passed in and withdrawn, blackened with soot, or unscorched, according to the state of the furnace, indicating the low temperature within the tubes, and their utter uselessness *as steam generators.*

Fig. 76.



In speaking of the evils of the tubular system, these remarks have no reference to its application in locomotive boilers, where *coke alone* is used, and for this self-evident reason, that no hydro-carbon gas or fuliginous flame has there to be encountered. In the tubes of the locomotive there is, in fact, no chemical or practical reason why the heat may not be abstracted from the products with the greatest rapidity.

With reference to the size and sectional area of the tubes, we even deceive ourselves as to what that area practically is. When, for instance, it is intended to give an area of 2 or 3 inches, it will not be sufficient merely to provide tubes of 2 or 3 inches diameter. Allowance must be made for the effect produced by the rapidity or *pressure* of the body, (whether it be flame, gas, air, or water,) forcing an entrance into a restricted orifice. The true and available area, that which directly influences the mixing operation of the several bodies simultaneously forcing themselves through the orifices, will then be, not as at A in Fig. 76, but as at A′. Thus, in effect, a tube of three inches of internal area will practically have one of but 2½ or 2 inches, and so in proportion to the size of the tube, and the amount of pressure exercised by the current. So little, however, has this been considered, that not unfrequently the ferrule, or iron ring by which the tubes are fastened to the face-plate, is inconsiderately placed *within their orifices;* thus still more seriously contracting the working area.

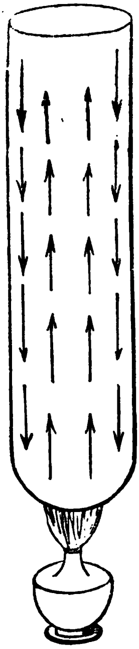
Looking, then, at the practical effect of these numerous narrow orifices, and the diminution of the temperature, consequent on its division, it would be impossible for ingenuity to have devised a more perfect mechanical mode of effecting that rapid and intimate contact between the flame and *the incombustible gases,* described by Sir H. Davy as being so injurious to the continuing high temperature of that flame, and, in a word, so effective in its extinguishment.

The inference which this inquiry leads to as regards the high temperature required,—1st, for the ignition, and 2ndly, for the sustained existence of flame is, that the tubular system is chemically, mechanically, and practically a destroyer of both.

CHAPTER X.

OF THE CIRCULATION OF WATER IN THE BOILER.

Fig. 77.



THIS important branch of the subject—promoting circulation in the water in evaporative vessels—appears to have hitherto received but little attention; yet promoting circulation is virtually promoting evaporation. Mr. Perkins proved by numerous experiments how much evaporation was increased by an unembarrassed action of the ascending and descending currents of the water: since then, no further effort has been made in that direction. If sufficient space be allowed for the action, the ascending and descending currents will of themselves take such directions as are most favourable for their respective function, as in Fig. 77, where an ascending current is seen in the centre, and a descending one on the sides.

Dr. Ure observes, "when the bottom of a vessel containing water is exposed to heat, the lowest stratum becomes specifically lighter, and is *forced upwards by the superior gravity of the superincumbent colder and heavier particles.*" Here we have the correct theory of circulation: no particle, or stratum of water or steam, (whatever may be its temperature,) being able to ascend, or change its position, until some colder or heavier particle is present, to take its place and "*force it upwards.*" This is the *rationale* of all motion in gaseous, or fluid bodies, arising from the *mere difference of specific gravities.* Thus, when we speak of atoms ascending, we must be considered as meaning their being "*forced upwards,*"—ascending being a compulsory, and not a voluntary, act. This elementary view of the motion should be kept in view, as it is the basis of all that follows; and as we are too often led astray when considering the *ascending* body of steam or water, but neglecting that *descending* body by which it is to be "*forced upwards.*"

In the case of *solids,* heat passes from atom to atom by *conduction,*—no perceptible change taking place in their relative bulk, weight, or position. In the case of a *fluid,* the entire mass being put into motion by its intestinal currents, circulation is continued, and ultimately the temperature of 212° is obtained, which has been termed the boiling point.

We have now to examine the class of motions and currents which are the result of this boiling operation. If we could suppose that there was no motion among the particles of water during the act of boiling, and that the atoms of *steam alone* rose to the surface on being produced,—in such case, circulation would be unnecessary, and the contraction of the water spaces in boilers would be a matter of no importance, as water would then be always present on one side of the plate to receive the heat transmitted through it from the other: such a state of things, however, is contrary to the laws which influence the change of temperature in fluids.

So far as regards the motion in water, *previous to ebullition,* it has been commented on by all writers on the subject. The act of boiling, however, creates a species of currents of an entirely different and important character. These have not received due attention, yet they are the most important, inasmuch as they influence not only the amount of evaporation, but, as will be shewn, the *durability* of the boiler itself.

With reference to the movements among the particles in water, it is a mistake to suppose they will descend in the same *vertical lines* in which they had ascended, as a shower of rain would through the opposing atmosphere. Such a direction would be impracticable on account of the resistance of the ascending currents of both steam and water, caused by ebullition. This may be illustrated by the annexed drawings. Fig. 78 represents a supposititious case of the particles of water on reaching the surface, turning and descending in the same vertical lines in which they had ascended. Fig. 79 represents the ascending particles of water *flowing along the surface to the coolest and least obstructed part for their descending course.* This is what takes place in all boilers.

Fig. 78.

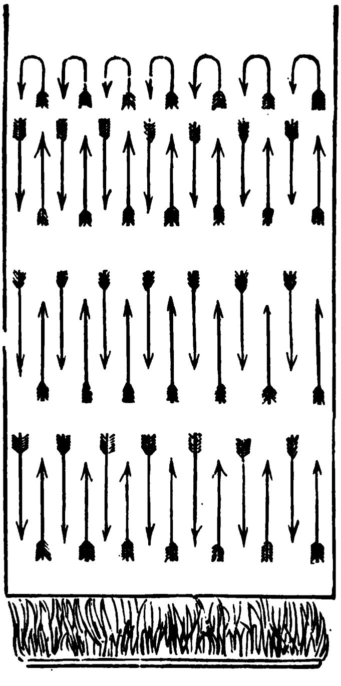
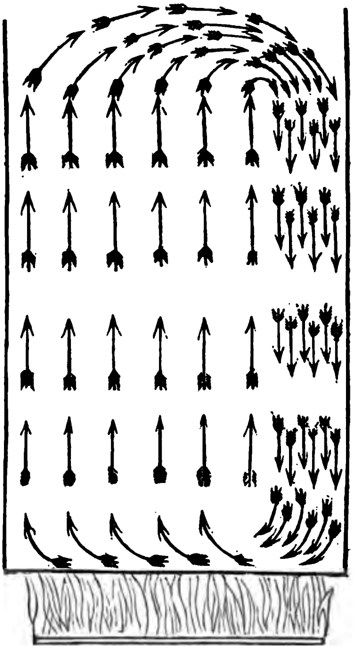


Fig. 79.



When heat is first applied to water, the uniformity of the motion is the mere result of *diminished specific gravity,* that being then the *sole motive power. After ebullition,* however, a new state of things is created. The columns of rising steam obtain great physical power, violently and mechanically forcing upwards the water which comes in their way. Vertical streams are thus induced, *putting in motion a body of water far greater than would be* *required for merely taking the place of that which had been converted into steam.* Now, as bodies or streams of water, commensurate with these continuously forced upwards, must necessarily return to prevent there being a vacant space, it is for these *returning or downward currents*, of what may be called *surplus water*, that we are called on to provide both space and facility.

The difference in the character of the currents *before* and *after* ebullition are shewn in the annexed figures. These may be well observed in a glass vessel, of the shape here indicated, and about 4 or 5 inches wide, suspended over the flame of an Argand burner. Fig. 80 represents the uniform motion which takes place *before* ebullition. Fig. 81 represents the water *after* ebullition in its descending and revolving currents, *forcing the rising columns of steam aside from their vertical course*, as marked by the arrows. These motions, which are not perceptible if the water be free from foreign matter, will be seen on throwing in a great number of small bits of paper, so as to occupy all parts of the water. The entire mass will then be exhibited in violent and revolving currents—the ascending steam occupying one side, and the descending body of water rapidly descending in some other part, but manifestly *occupying a much larger area of the vessel than the ascending portion.*[*]

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[*] The extraordinary body of water forced upwards, and the important effects produced by the induced currents, manifestly required further investigation. As they exerted a great influence on the amount of circulation and evaporation, I pursued the inquiry into the cause of these currents upwards, and the increased body of water which necessarily required facilities for a downward current. The result of these experimental investigations was ascertaining that the prevailing theories respecting vaporization, ebullition, and evaporation, were entirely erroneous. In fact, that this important branch of the subject had not been duly examined, and that the causes of those peculiar movements in water had hitherto escaped observation. Here, then, is an unexplored and interesting field of inquiry, which will amply repay the labours of future investigators. In the event of its not being undertaken by others, I propose hereafter giving the result of my inquiries in a separate treatise.

Fig. 80.

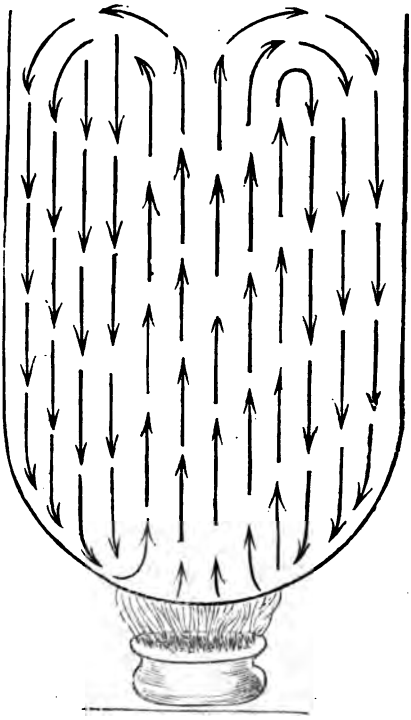
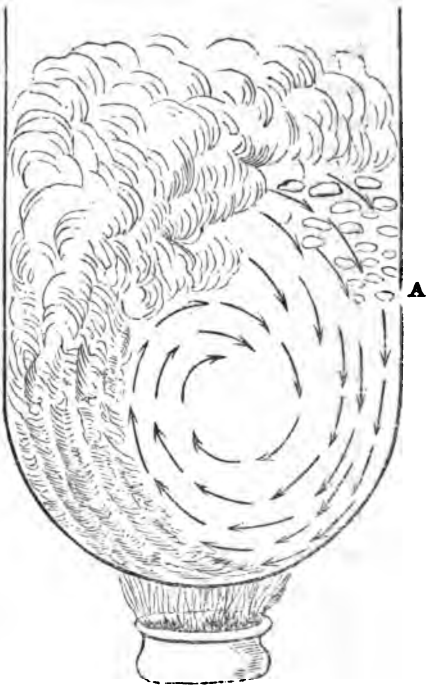


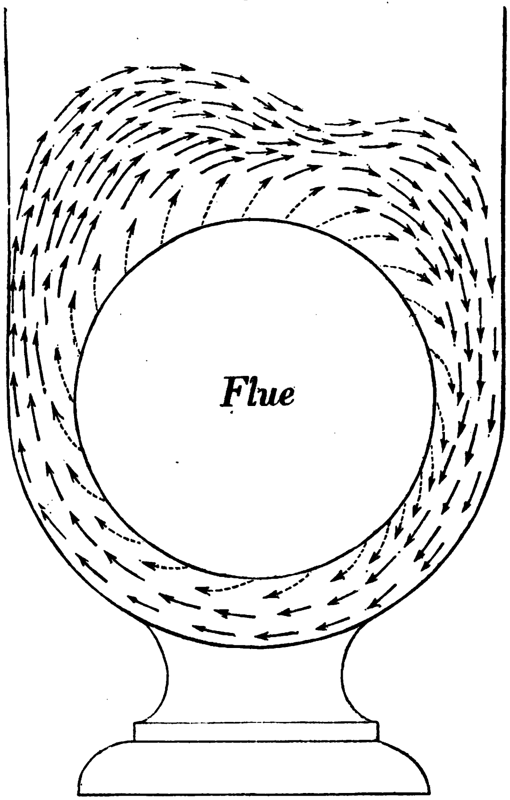
Fig. 81.



So great is the ascensional energy and velocity of the rising steam, and the extra water forced before it, that numerous globules are borne along by the current, and carried even downwards. These may be observed at A, Fig. 81, in their slow oscillating motion, struggling to return upwards through and against the force of the descending water. These movements are highly instructive, and should be well examined, since, without an accurate knowledge of them, we cannot have a right conception of what is required for giving a due circulation to the water, and arranging the flues and water spaces in boilers to enable those motions to be completed.

The influence exercised by the descending body of water was strikingly illustrated in an experimental tin boiler, 12 inches long, with a single flue running horizontally through it, the water being heated by the flame of a large laboratory gas lamp. The boiler being open at the top, the movements of the steam and water were thus ascertained, as shewn in Fig. 82. So soon as the ebullition became strong, the water spaces round the flue appeared insufficient to allow the steam to ascend, and the water to descend, equally on both sides. The consequence was, that much of the water forced up by the steam on the one side, was carried over by its violence, and descended on the other, thus making a circular course round the flue, and forcibly carrying along with it much of the steam that came in its way. This circular motion is shewn by the dotted arrows representing *the steam*, and the plain arrows, *the water*.

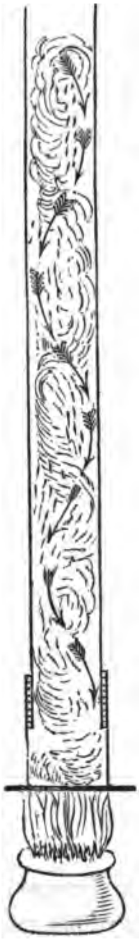
Fig. 82.



With the view of observing the injurious consequences of restricted water-ways, a very useful class of observations may be made by using a tall narrow glass as in Fig. 83, attached to a tin or iron vessel, with a flat bottom, to receive the heat from an Argand burner, or spirit lamp.

Here the *descending water* is so obstructed by the joint columns of *ascending steam and water*, that both are thrown into great confusion:—their respective currents continually changing sides, and the progress of evaporation considerably delayed. We here obtain a clear practical view of what must take place between the flues or tubes of boilers, with their usually *restricted water-ways*.

Fig. 83.



The violence and intermittent action which ensues where separate channels or sufficient space are not available, will be well illustrated in the following experiment: Fig. 84 represents two long glasses, each 2 inches wide by 18 inches long, A and B connected by means of a tin apparatus C and D, at top and bottom, leaving the communication open above and below; the whole being suspended over a fire, or circular series of gas jets producing a strong heat. On the heat being applied, a current of mixed steam and water will be seen ascending in one glass, and descending in the other, as indicated by the arrows. There being here no confusion or collision, a state of things will be produced highly favourable to the generation of steam; the colder water finding easy and continued access to the heated bottom of the vessel at E.

If, however, the communication between the two glasses be cut off by inserting a cork or plug in one of the glasses, as seen at P, Fig. 85, the circulation in glass B will be suspended, and the glass A will then have the double duty to perform of allowing the rising steam to reach the surface, and the descending water to reach the bottom at E. The previous uniform generation of steam will then be succeeded by an intermittent action,

Fig. 84.

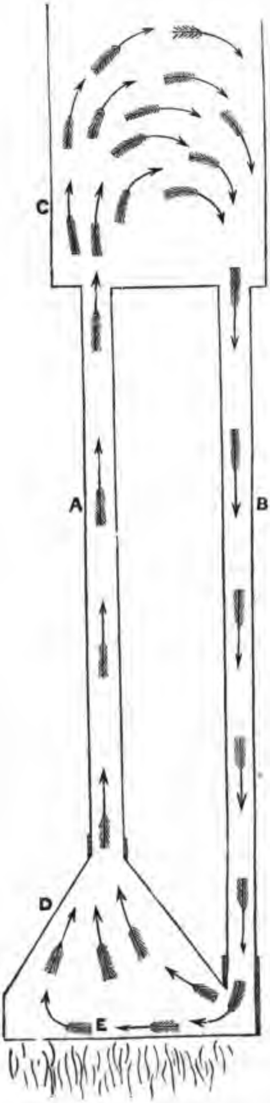
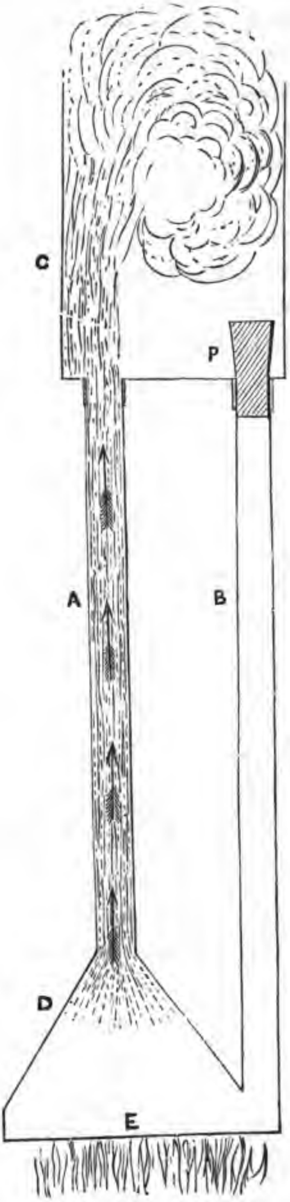


Fig 85.



explosive violence alternating with comparative calm and inaction, clearly indicating that the latter is only the interval of accumulating force to be discharged by the former. The *rationale* of this intermittent action is, that the water being obstructed in its descent, the steam is necessarily delayed or accumulated in the lower chamber, and only discharged at intervals. The motions exhibited in these intermittent changes are little understood, and have not been examined either scientifically or practically; yet this branch of hydrostatics merits the most serious investigation in connexion with the construction of large boilers.

Again, this accumulated steam getting sudden vent is discharged with great violence, literally emptying both the glasses and lower chamber. An equally violent, but more sudden, reaction of course follows, and a large body of colder water as suddenly rushes down to fill the space vacated. An interval will then necessarily be required to raise the temperature of this large supply of colder water, and restore the previous state of ebullition.

Here, then, we have a natural and physical cause for the intermittent action on the small scale which takes place in boilers on the large scale, where free circulation is impeded by the want of adequate space. Here also may be seen the true source of *priming* in boilers where the act of ebullition is violent.

In this experiment, although there was nothing to intercept the steam and water in their ascent, the intermittent action continued at intervals of one or two minutes. At each irruption, the steam and water were forced to a considerable height, and on its return, striking downwards into the vessel, shaking the apparatus with such violence as apparently to threaten its destruction, the blow received internally being accompanied with a noise as if a heavy body had fallen on the floor. From the great violence and explosive character of the ascent, when the intermittent action occurred, it was manifest that had the vessel been a close one, no safety-valve would have been sufficient to relieve the outburst of these irruptions.

The wholesome action of a safety-valve depends on a supposed uniform and progressive increase of volume and pressure of the steam; yet, practically, nothing of the kind takes place: all is intermittent, indicating a succession of eruptive efforts in discharge of the accumulated steam. In truth, after ebullition has begun, the whole process is intermittent,—ebullition itself is an intermittent, but hitherto unexplained, action. Here then we have a practical exemplification of at least one of the causes of these explosions which have latterly become so frequent. These experiments were repeated with numerous alterations in the relative length and diameters of the glasses, each presenting some new phase of the process of vaporization, indicating that a highly important field still remained for investigation, and bearing practically on the subject of the areas required for the efficient circulation of the water and generation of steam. The subject, however, is too extensive and too important to be here entered on, and must be examined more at length than would here be practicable.

CHAPTER XI.

ON THE CIRCULATION OF THE WATER IN RELATION TO EVAPORATION, AND ITS INFLUENCE ON THE TRANSMISSION OF HEAT.

WITH reference to the currents in water caused by the application of heat, the first point for consideration practically is, the direction in which the atoms of water approach the plates where they are respectively to receive heat.

Remembering that before any particle of water can leave the heated plate, and rise to the surface, *as steam*, it must be "*forced upwards by some colder and heavier particles.*" Unless, therefore, a due succession of such particles be enabled to take their places as rapidly as others have received the heat due to their vaporization, the plate itself cannot be relieved of its heat, and consequently, evaporation must be retarded.

To illustrate the direction in which the particles successively approach the heated plate, Fig. 86 represents a vessel of water — the heat being applied *from beneath.* The question here is, whether the colder atoms which are to take the places of the atoms of vapour, generated at the point A, will approach that point in the direction of the arrows B, C, or D. From what has been just shewn, it is manifest they cannot arrive in the *downward direction* of B, and must necessarily come in that of either C or D.

Fig. 86.

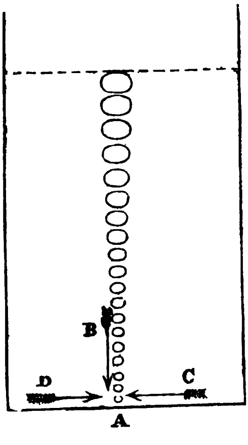
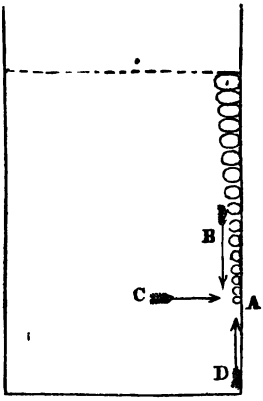


Fig. 87.



Again, suppose the heat be applied *laterally, as to the side plates of a furnace.* The question then will be, whether the colder atoms will approach the point A, as in Fig. 87, in the direction of the arrows B, C, or D. For the same reasons it will be seen that it must be in that of either C or D. This is manifestly in favour of *vertical,* rather than *horizontal* surfaces, as practically has been proved in the case of vertical tubes. This advantage may be accounted for by the fact, that the currents of the atoms of vapour, and that of the water about to be converted into vapour, will then be running *in one and the same direction,* and consequently, without obstruction or collision.

Now as vaporization does not depend on the quantity of heat *applied to* the plate, but on the quantity *taken from it,* the amount of evaporation will be determined by the rapidity with which the colder atoms of water obtain access to the heated plate. Hence we see how more important it is to study the means of giving that access of the *water to the one side* of the plate, than of *heat to the other.*

The annexed figures will illustrate, practically, the direction in which the colder water obtains access to the *sides* and *crown plates* of a furnace:—the arrows representing the atoms of water, and the dotted lines those of the rising steam.

An important question is here raised,—do the atoms of water approach the plate in the direction of the arrows as in Fig. 88 or Fig. 89. Every thing goes to shew that it must be as in the latter. We here then find that the *crown or horizontal* plates can be supplied from the *vertical water spaces alone;* and hence the importance of making those channels so large, and conveniently arranged, that the water may reach them in full current and quantity. This also accounts for the fact that the crown plates are the most liable to injury from being over-heated. The side plates next the fuel on the bars, becoming over-heated and burnt, we shall see, is referable to a different cause.

Fig. 88.

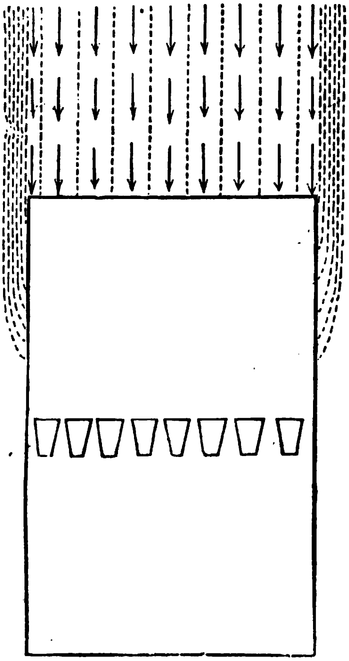


Fig. 89.

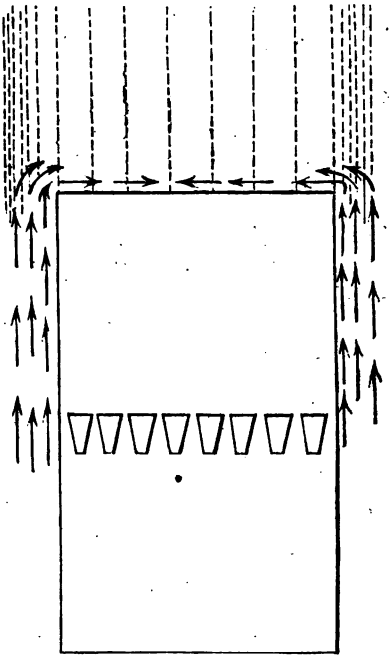
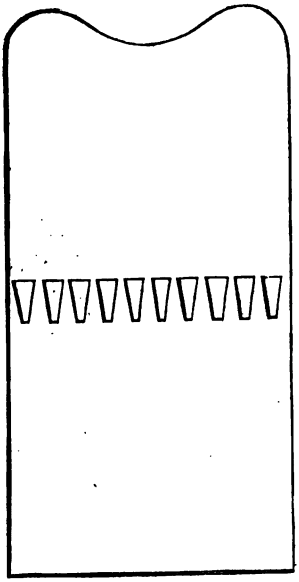


Fig. 90.



The crown plates of a furnace are then the most liable to injury from the double cause of being exposed to the greatest heat, by direct impact of the flame, and from the water having greater difficulty of access to them, as shewn in Fig. 88.* This causes them frequently to bulge under the pressure of steam, as in Fig. 90. This bulging on one occasion occurred in the first voyage the vessel had made; nevertheless, no inconvenience resulted from it;—the iron having been of good quality, the boiler remained in a state of perfect efficiency for many years; and when ultimately broken up, the bulged part was as sound and thick as it ever had been.

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* This has been well illustrated by Mr. Fairburn in a paper read to the

On this it may be observed, that if there be any obstruction or sluggishness in the water reaching the crown plates (on its rising from the vertical water-ways), the violence of the upward current of steam will carry it in the direction of the arrows in Fig. 91;—thus leaving the centre of the crown plate in *contact with steam rather than water*, and by which it necessarily becomes over-heated.

Looking to the direction of the water on passing from the vertical side spaces to the crown plates, the shape, as in Fig. 92, would appear most favourable for aiding the access of the water—(the arrows shew the direction of the water, and the dotted lines that of the steam). The cylindrical shape, perhaps, offers the most advantages as regards direction of the water, and the resisting power of the plate.

Fig. 91.

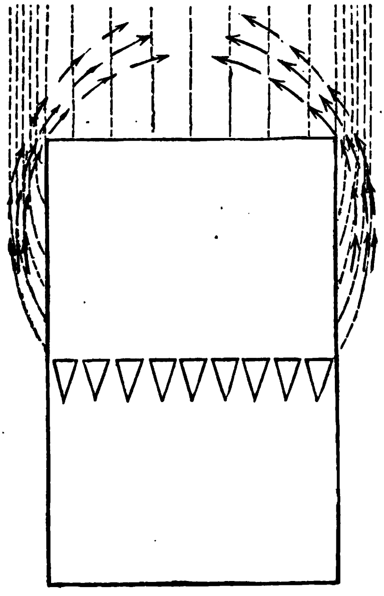
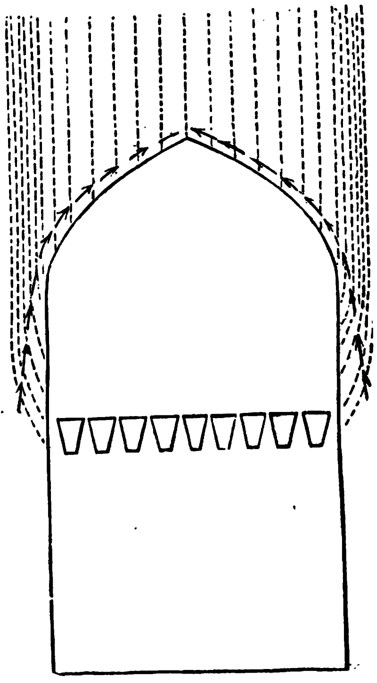


Fig. 92.



British Association at Hull, detailing some very interesting results of researches made for the purposes of determining the strength of locomotive

The inferences to be drawn from these facts are,—*First*, that every possible facility should be provided for enabling the steam to reach the surface of the water without loss of time or temperature. *Secondly*, that ample space should be given, at *the ends or sides, or both*, for the large *returning body of water*, which had been forced upwards by the violence of the ascending columns of steam. *Thirdly*, that similar and adequate means should be provided to enable the water *to spread along the bottom*, in its course to supply the numerous vertical spaces between the furnaces.

We will now consider the internal arrangements of marine boilers, with reference to the circulation of the water. Previously to the introduction of steam power into sea-going vessels, boilers were simple in their construction,—the water forming one undivided mass within which its intestinal currents had free scope to act, taking whatever course was most favourable and in accordance with their temperatures. The waggon boiler of Watt, and the dome shaped colliery boiler, may be considered as types of this class. In such, the question of circulation had no practical application. The employment of the steam engine for marine purposes, first rendered it necessary to make a change in the internal arrangements of the boiler, as well for economizing space, as for prvoiding adequate heating surface. This produces the system of *internal flues, of considerable length, or lineal run*, corresponding with the great length of brick flues, under and round land boilers. Instead of one undivided mass, the water was necessarily thrown into numerous deep narrow avenues, and thin films, with conflicting internal courses, and multiplied obstructions.

Here, then, was a new system involving great practical

boilers. In the boiler which exploded at Long-side, "Considerable stress," he observes, "had been laid upon the weakness of the stay which united the flat surface of the boiler to the sides of the fire box. The experiments made, however, clearly indicated that the fire box stays were not the weakest parts, and that there was *more to fear from the top of the furnace, which, under severe pressure, was almost invariably the first to give way.*" This is the first time any doubt has been thrown on the comparative strength of this part of the furnace.

changes, not only in the direction of the heated products from the furnace, but of the currents of both steam and water. These changes, however, appear to have excited no attention. It was said (and in the same loose manner) that the water would find its way to the heated flue plates, just as it was said that the air would find its way to the fuel, and the steam to the surface, *without considering what those ways were, or ought to be, and whether they were provided.*

The extent to which the heat will be taken from the plate is next to be considered. Mr. Sewell,* among many useful remarks, has some which suggest important points of inquiry in connection with marine boilers. "No matter," he observes, "how ably the furnace performs its duty, if the heat given off from the fuel cannot *be taken up as rapidly as it is produced,* then of course economy ceases." This, no doubt, is true, but he has left unnoticed the more important point, namely,—*by what is the heat to be taken up?*

Again,—"Where the power of *convection* is much greater than the power of *absorption,* then the heat evolved during combustion, is carried off without effect." This is also true; but we are still left in doubt,—*by what is the heat to be absorbed?*

Now this absorption cannot be in *the plate.* In a well-constructed boiler, where adequate means of circulation of the water are provided, *there can be no absorption in the plate,* which is, or ought to be, the mere conveyor or *transmitter.* The very term absorption implies, not merely *receiving,* but *retaining,* the heat, and which certainly is not the function of the plate.

This distinction involves considerations of the last importance. By confounding the *heat transmitter*—the *plate*—with the *heat absorber*—*the water,*—we fall practically into innumerable errors; not the least important of which are the overlooking the question of the currents and circulation of the water; and the being satisfied with merely *providing a large aggregate of surface;* hence concluding, that we had also provided a commensurate *absorbing and evaporative power.* Errors of this kind lead to a neglect of the express function of the plate itself, which is merely *to transmit* what is given to it *on the one side,* to that which will receive it *on the other.*

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* *Elementary Treatise on Steam and Locomotives,* by John Sewell, L.E., Vol. I. John Weale.

In addition then to the power of *convection,* or carrying the heat through the flues,—which belongs to the gaseous products of combustion,—and the power of *transmitting* the heat,—which belongs to the plate,—there is *the third power,* namely, that of *absorbing and retaining the heat,* and *which belongs exclusively to the recipient, which should be water.* Now a right understanding of these separate functions and duties is absolutely necessary before we can determine the relation which the size or surface area of any one part of a boiler should bear to the rest. It is from neglect of these distinct functions, and the confounding the one with the other, that we so often err in giving an unwise rapidity to the convecting character of the gaseous products, and an injurious curtailment of the convecting range or run.

On this *absorbing* faculty, and still without defining to what it belongs, Mr. Sewell observes—"Much of the comparative economy of boilers depends on their absorbing power." Here we are left under the impression that this absorbing faculty is a function of some part of *the boiler,* which certainly is not the fact.

Now it is more important that we investigate *the absorbent power of the recipient, than that of the plate.* All that the plate requires is, that its *transmitting power*—its proper function, *be brought into action.* On this head M. Peclet correctly observes, that, "under ordinary circumstances, the quantity of heat which a metal plate has the power of transmitting, is far greater than what it is really called on to transmit!"*

To expect then that the plate will exercise a greater power of *transmitting* heat to some other body, than that body possesses for *receiving and absorbing it,* would be a physical absurdity. As well might we expect that a *larger* quantity of water would pass through a porous body than could be contained in the space in which it would be received; or that the steam from the engine cylinder could be discharged into the condenser, in the absence of a sufficiency of water, or space, there to absorb or receive it.

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* "Nous avons vu que dans les circonstances ordinaires, la quantité de chaleur que peut transmettre le métal, est beaucoup plus grande que celle qu'il a réellement à transmettre."—*Traité de la Chaleur.*

Mr. Craddock, in the course of his published Lectures, has introduced a new feature in the question of the transmission of heat, by drawing a distinction, as to temperature, between the two surfaces of the plate. "It must be borne in mind," he observes, "that it is the *exterior surface*, along or over which the gases pass, and the *difference of temperature between such surface and the heated gases passing over it*, will depend the rapidity with which the latter will impart their heat to the former." This assuredly is not the case.

It may be asked, Why draw a distinction between the temperature of the *exterior* and *interior* surfaces of the plate (as if there could be any important difference), while no notice is taken of that on which the temperature of *both its surfaces* really depends,—namely, the *character of the recipients of the heat?*

In this dictum we have proof of the prevailing error of assuming that the recipient of the heat will *always be water*,—that it will *always be present*,—and *always in contact with the plate.* This, however, is pre-supposing the very thing at issue,—the very fact which experience denies. If indeed such were really the case, it would be a matter of perfect indifference what might be the degree of heat to which the plate, or its external surface, might be exposed; inasmuch as all the heat that possibly could be presented to it, would pass to the water as rapidly as it could be received, and no possible injury could take place. *The temperature of the plate, in truth, only becomes an object of attention when there is a want of adequate circulation of the water*, and consequently, a deficiency or delay in its obtaining contact with the heated plate surface. In such case, *steam* must necessarily be compelled to act the part of the recipient, by occupying the place where *the water* should have been, but whose function it is so ill qualified to discharge.

It is here manifest that as the heat absorbing power of *steam* is so inferior to that of *water*, a much less quantity will be taken up, in given times, by the former than by the latter. Again, since no more heat can be *transmitted through the plate, from the one side than can be taken from it by the recipient* on the other,—the *transmitting* power of any given surface must be absolutely dependent on the *absorbing* power of that recipient, whether it be oil, water, steam, or air.

Water, we have seen, will absorb more heat than steam. The quantity taken up, therefore, will be regulated, not by the "difference of temperature between the plate surface and the heated gases passing over it or along it,"—but by the *capacity of the receiving body, whatever it may be, for absorbing it.* If, however, from any circumstance, the water be prevented or delayed *in gaining access to the plate,* the steam will in a like degree be obstructed *in leaving it;* the presence of the former being the very means by which the latter will be effected.*

Thus the heat which, in such case, cannot be taken *from* the plate, must remain *in* the plate,—its function being then changed from that of a *transmitter,* to that of an *absorber;* the whole process of evaporation being then deranged, as will be seen when we come to the consideration of the causes which affect its *durability.*

Again, the mechanical structure of the two bodies (water and steam), has much to do with the quantity of heat absorbed. *Water* is composed of an infinity of atoms so minute as to be utterly inappreciable. Now this very circumstance multiplies to an extraordinary extent, its points of contact with the heat transmitting surface. *Steam,* on the other hand, is a series of inflated globules, each of which is 1800 times larger than the atom of water from which it proceeded; necessarily producing greater difficulty of access to the plate, and fewer points of contact with its surface.

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* The celerity with which heat is communicated from hotter bodies to colder ones, when all other things are equal, is proportional to the *extent of contact and closeness of* communication between the bodies.—Thompson *on Heat and Electricity.*

This very fact, then, supplies a scale by which we are enabled to appreciate the superior facilities of contact which water possesses over steam—if due circulation be obtained; and the greater rapidity with which the former is enabled to take up heat, and its enlarged capacity for retaining it.

We have next to consider the relation which circulation has to the durability of the plate itself.

CHAPTER XII.

OF THE CIRCULATION OF THE WATER IN RELATION TO THE DURABILITY OF THE PLATES.

HAVING considered the circulation of the water as regards evaporation; distinguishing the separate functions of the heat *transmitter*, and the heat *recipient*, we have now to examine its bearing on the durability of the plates.

In the first marine boilers, the flues were made *deep with narrow water spaces*, usually about four inches wide. The object then was to combine the two essentials,—adequate length of run in the flue, with sufficient heating surface. Among the disadvantages of this arrangement of the flues was, the recurrence of injury to the plates in the region of the furnaces by becoming *over-heated*. Although this evil of over-heating continues to be experienced, the direct cause of it has remained without due inquiry. Its recurrence was usually attributed to neglect on the part of the fireman, or the want of sufficient water in the boiler; hence more importance was attributed to the necessity of having "careful and experienced stokers," than to the remedying the defective construction of the boiler itself.

If the water indicated a level *above the flues*, all was considered right, and no thought was given to the possibility of its being deficient *below or around them*. Yet experience has shewn, that although everything indicated a proper height of water in the boiler, the plates, particularly those connected with the furnaces, were, nevertheless, subject to be over-heated and injured. In such cases, if the iron was laminated, or otherwise of inferior quality, it became cracked, or burned into holes. This state of things was strikingly illustrated in the boilers of the "*Great Liverpool*" steam ship, on her first voyage to New York, in 1842. The engineer, observing the side plates of the furnaces constantly giving way, — some bulging and others cracked and leaking, and even burnt into holes, although there was always a *sufficient height* of water in the boiler, suspected something had interfered to keep the water from the plates, and with the view of testing it, introduced an inch iron pipe from the front into the water space between two of the furnaces. This at once brought the source of the evil to notice, for although the glass water-gauge always indicated a sufficient *height of water within*, yet nothing issued through the pipe but *steam*, so long as the boiler was in full action.

This fact unmistakably shewed that the over-heating of the plates was unconnected with the duties of the fireman, and was the result of *insufficient circulation*, depriving the deep narrow flue-spaces of an adequate supply of water. There was then, manifestly, no remedy for this continually recurring evil, and a new boiler became necessary.

Here then was the exact case suggested by Mr. Murray,* when he says, "It is a point of the utmost importance that no part of the heating surface of a boiler should be so situated that the steam may not *readily rise from it* and escape to the surface; since the plate, *if left in contact with steam instead of water*, *becomes unduly heated and destroyed.*"

Now, we overlook the fact, that the only remedy against this source of injury is, providing adequate *circulation of the water*, since the steam cannot "*rise from the plate surface*," and must remain in contact with it, until *water or other globules of steam* take its place and force it upwards; consequently, if the approach of the water be slow, so must be the rise of the steam. There can be no vacuum; no interval between the approach of the one and the escape of the other. *Either water or steam* must be at all times in contact with the plate: the relative time, occupied by either in obtaining this contact, will therefore decide the question of the amount of evaporation, and the temperature of the plate.

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* *Treatise on the Marine Engine*, by Robert Murray, C. E. London, John Weale.

The important point then for inquiry is, Why was the plate thus left in contact with steam instead of water? There was here no apparent impediment to the steam rising to the surface. There was, however, as we shall see, extraordinary difficulty of access to the water to *dislodge the steam*; and, as Dr. Ure observes, it must remain, until "*forced upwards by colder and heavier atoms of water.*"

As the details of this boiler of the "*Liverpool*" will afford opportunities for comment, much of what is practically necessary for promoting circulation, they are here annexed.

Fig. 93.

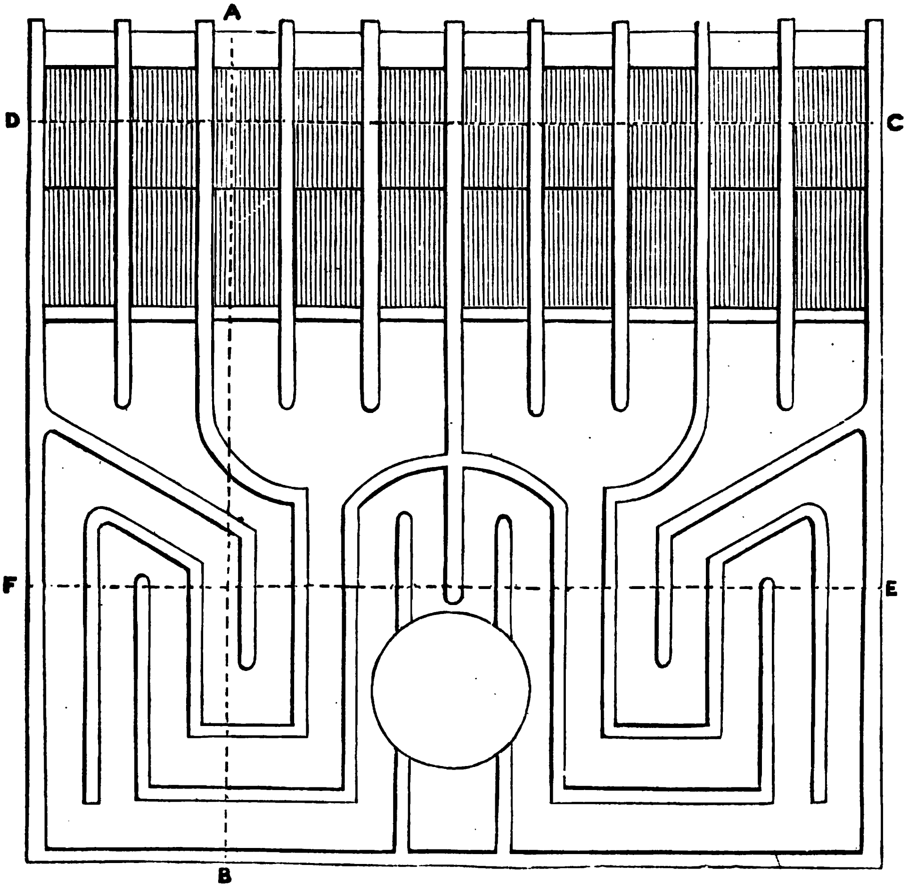


Fig. 93 is a plan of the boiler, shewing the ten furnaces, and the narrow water-ways separating the series of narrow flues.

Fig. 94 is a section from A to B, shewing the water spaces of 5 feet deep by 4 inches wide, and the direction in which the water approached the side and crown plates of the furnaces. The *bottom horizontal* water-space is here seen, of *but 5 inches deep*, and from which *all the vertical spaces were to be supplied.* This bottom space was also found to be much obstructed by sediment and other deposit. Here we see the direction the water had to take in its *downward* course was through one narrow four-inch space; and then to be distributed over the bottom area of above 500 square feet in its way to the vertical spaces between the furnaces and flues.

Fig. 95 is a section across the furnace end of the boiler, from C to D, shewing the eleven narrow water spaces, and into one of which the trial-pipe was introduced, as already mentioned.

Fig 96 is a cross section of the after-part of the boiler, from E to F, shewing the sixteen water spaces between the flues.

It may here be observed, that the side plates of the ten furnaces, which, as being the hottest, required the largest supply of water, were, necessarily, the worst supplied, being the *farthest from the narrow downward current at the back end.* It is here manifest that the furnace side-plates could not have been adequately supplied with water, to take the place of the great volume of steam generated from their surfaces, and, consequently, that *the steam must have been retained in contact with them.* It can no longer then be a matter of surprise that the sides of the furnaces became over-heated and injured.

In this boiler, the ten furnaces being all at one end, the water taking the coolest place for its descent, would naturally flow along the surface from front to rear, as shewn by the arrows, Fig. 94. (The construction of this boiler, as regards what takes place *within the flues*, will be further noticed in the Chapter on "*Draught.*")

Fig. 94.

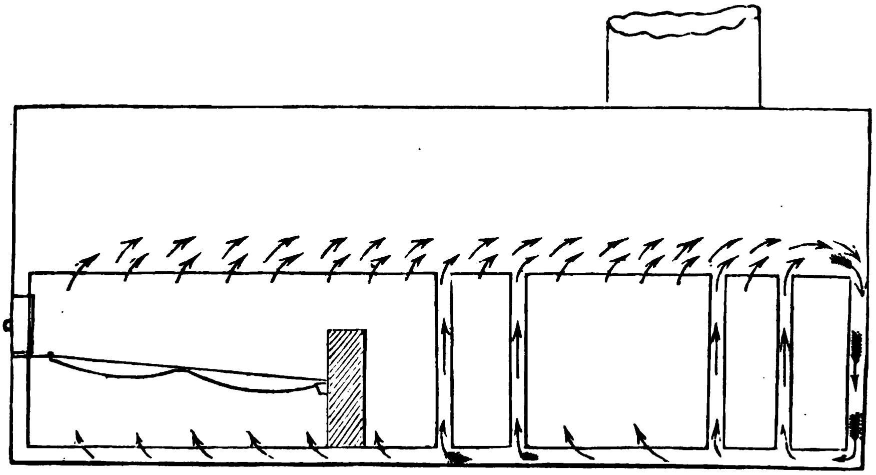


Fig. 95.

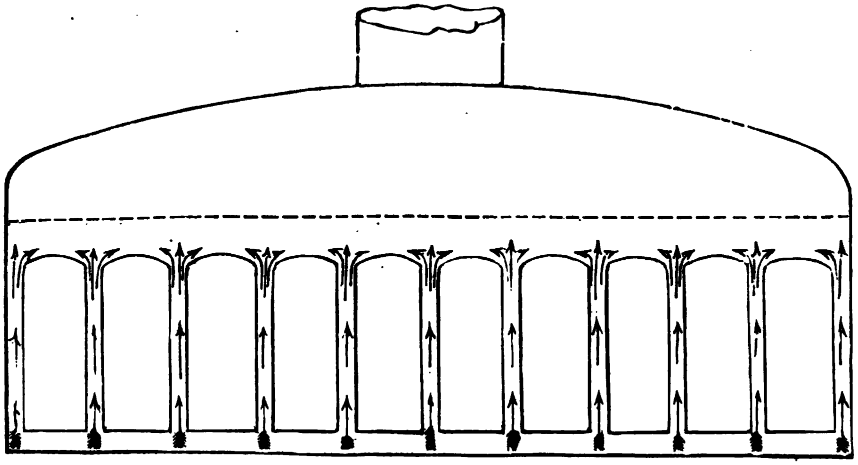
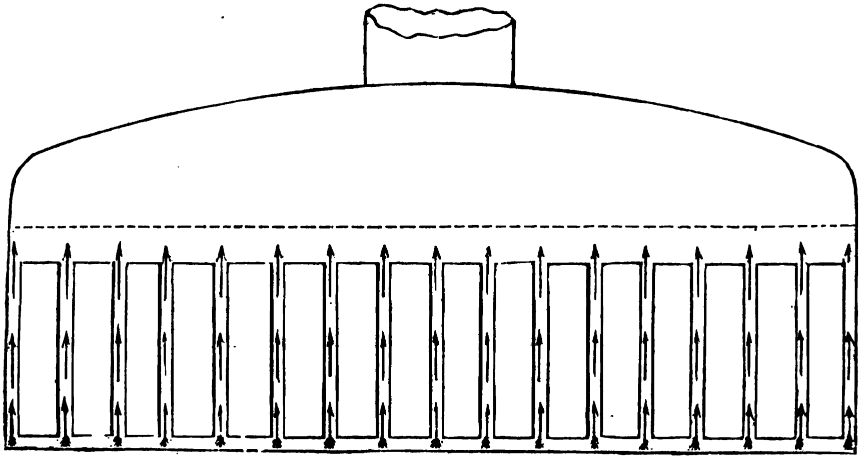
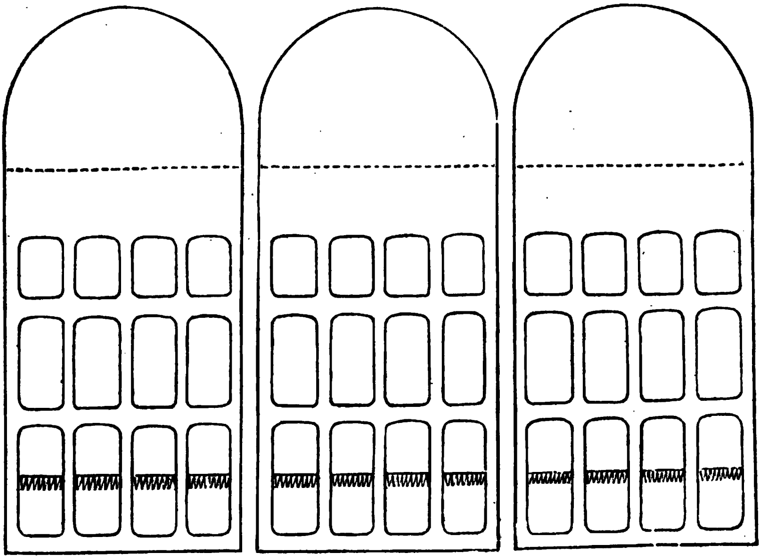


Fig. 96.



The first boilers of the "*Great Britain*" Steamer give another illustration of the difficulty the water had to encounter in obtaining access to the vertical spaces, and the thirty-six crown surfaces of that number of flues as shewn in Fig. 97. The lower or furnace range of the triple tiers of flues was 5 feet deep, the second 4 feet, and the third 3 feet; the numerous vertical water-ways, though *but* 4 *inches wide,* had an aggregate of no less than 12 *feet deep.* No adequate or separate space, however, was provided for the *downward* current of the great quantity of water that must, momentarily, have been required to supply so many *ascending* currents; the consequence was, that the ascending steam had to struggle against the descending current of the water, while the latter, in its way, was obstructed in reaching the plate-surface. Thus, the rapid generation of steam, and free access of the water to the plates, were both impeded in their respective functions.

Fig. 97.



Another source of injury supposed to arise from the *thickness of the plates*, here merits attention. On this head Mr. Craddock, advocating the use of *thin* plates, but overlooking the question of circulation, and the character of the recipient of the heat, falls into the common error. "We know," he observes, "that boiler-plates of ⅜ or ½ inch thick, are often heated very considerably, *on their exterior, above the temperature of the water in the boiler*. This is known to take place to such an extent, practically, as rapidly to deteriorate such parts of the boiler."

How this extraordinary alleged fact has been ascertained does not appear. Yet, a dictum, so opposed to all experience, should have been supported by experiments or proof.

Now, this supposed heating and deterioration of the plates, must either be a *constant* or an *occasional* effect. The former, we know it is not. The latter, therefore, must have been the result of some unusual and disturbing cause, but which he has not explained. It is this cause which has been overlooked, and which here demands special inquiry.

No doubt, plates are often over-heated and deteriorated; assuredly, however, it has *not been owing to their thickness.* Indeed, when over-heating does occur, *thickness is a positive protection.* It may then be taken for granted, that, as to the plate being injuriously heated, such is absolutely impossible, *if the water be in contact with it.* This, then, is the practical point involved in the question of circulation.

Further, he observes, "We have not good *data* from which to draw unexceptionable conclusions as to the absolute *difference of temperature* between the *external* surface of the boiler-plates, or tubes of different thicknesses, with an intense fire acting on them *and the water they contain.*" Certainly we have no such *data,* since no appreciable difference can possibly exist between the temperature of the plates, *and the water in contact with them.*

The true question here is, *whether the water was or was not in contact with the plates?* It is manifestly the overlooking this all important point, or the assuming that the water had such contact, in fact, begging the whole question, that has led to the error of drawing a distinction between the temperature of the two surfaces of the plate. Such a distinction, however, would be directly at variance with the laws of conduction, as it assumes a degree of congestion of the heat on the one side, and of exhaustion on the other, although the distance the heat would have to travel would be but half an inch. This possible injury to iron plates, continuing to be thus asserted, demands a further inquiry.

Numerous authorities might here be quoted; it will, however, be sufficient to say, that had any such fact *been proved*, it could not have escaped the attention of Dr. Lardner.* On this head, he only confirms what the highest authorities have stated, when he asserts that a vessel cannot be injured by heat, so long as it contains any liquid; that is, *so long as the liquid is in contact with it.*

That the transmitting plate cannot be "unduly heated or destroyed," where the recipient of the heat is *water*, may be tested in many ways. Water may be boiled in an egg shell, or in a vessel, the bottom of which, though made of *card paper*, will not be injured. That the temperature of an iron vessel of even half an inch in thickness, containing boiling water, cannot be much, if any, above that of the water, may be tested by applying the fingers to it, immediately on being removed from even an "intense fire." In fact, the temperature will rather appear to *increase after its removal from the fire.* The reason is obvious: — the heat being so rapidly taken up and absorbed by the water, *its current through the plate* must necessarily be equally rapid. On removal from the flame, however, the *ex-*

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* "The absorption of heat," the Dr. observes, "in the process by which liquids are converted into steam, will explain why a vessel containing a liquid, though constantly exposed to the action of the fire, can never, while it contains any liquid, receive such a degree of heat as might destroy it. A tin kettle containing water may be exposed to the action of the *most fierce furnace*, and yet the tin, which is a very fusible metal, will remain uninjured. The heat which the fire imparts to the kettle is immediately absorbed by the bubbles (atoms) of water which are converted into steam, at the bottom, and rendered latent in them. So long as the water is contained in the kettle, this absorption continues; and it is impossible that the temperature of the kettle can exceed the temperature of boiling water.

terior surface, then receiving no further supply or increment of heat, is instantly reduced in temperature; the current through the plate then *becomes reversed, and passes from the inside to the outside.* The water side being absolutely the hottest, a new equilibrium is established, equal to that of the water at 212°.*

Fig. 98.

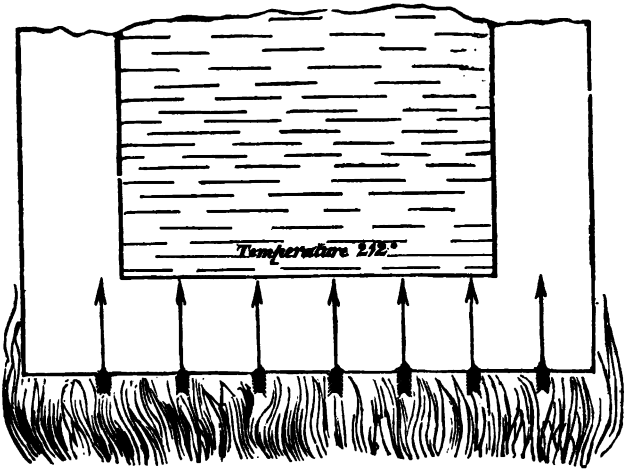
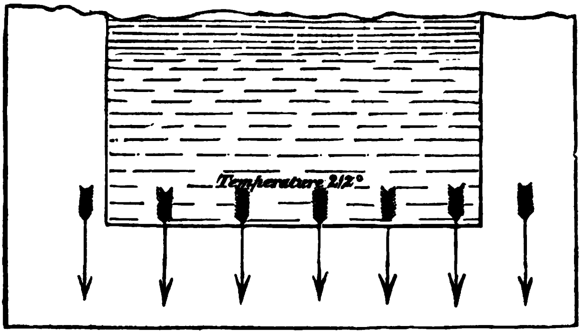


Fig. 99.



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* For the purpose of putting this to the severest test, an iron vessel with a flat bottom and half-inch thick plate was placed over a furnace, expressly constructed, so that it might be exposed to a very great heat from a coke fire, urged by a strong blast: the rapidity of the ebullition was extreme. It was so arranged, that it could be suddenly removed from the furnace, and the temperature of the bottom instantly ascertained by the touch of the fingers. This was done repeatedly, yet, on all occasions, it scarcely appeared to have the temperature of boiling water.

The figures opposite represent vessels of half-inch iron, both filled with water, in the act of boiling over a powerful flame. In Fig. 98, the course of the heat is shewn by the arrows passing from the flame through the half inch of iron to the water inside for the formation of steam. In Fig. 99, the vessel is supposed to have been suddenly removed from the flame ; the arrows shew the then *reversed direction of the current of heat* from the water side, where it continues at 212°, to the outside, where it would soon, otherwise, have been cooled by the lower temperature of the air.

As to the plate remaining at a safe and comparatively low temperature, there can be no doubt, seeing that oxidation or injury does not take place in iron, until it has reached that of redness, and which never can occur so long as water is in contact with it. When, therefore, the assertion is made, that plates have been heated so considerably above the temperature of the water as to be rapidly deteriorated, this could only be made on the assumption, that water was in contact with the plate, but which was not the case, as in the boilers of the "*Great Liverpool*" already mentioned.[*]

A conclusive illustration of the fact, that the plates are, in no way affected by thickness or temperature, is afforded by finding, that in breaking up old boilers, those parts which were exposed to the most intense heat and direct impact with the flame, have continued sound, and wholly undeteriorated when the water had free access to them.

With the view of testing the superior heat-absorbing faculty of water, numerous experiments were made: the result is the following tabular view, which sufficiently approximates the relative effect of the several classes of recipients to which the plates of a boiler may be exposed. Supposing then that the heat-transmitting power be taken at 1000°, the portion that will be absorbed, in given times, by the following recipients, may be estimated as follows: —

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[*] Dr. Ure gives a remarkable illustration of the little effect caused by the thickness of the plate, if the water be in contact with it ; stating that he had experimented with plates of twelve times the thickness of others without producing any injurious effect.

Nature of the recipient.	Heat received by the plate in given times.	Portion of the heat transmitted by the plate.	Portion of the heat remaining in the plate.
Water . .	1,000°	1,000°	none.
Water and Steam	1,000°	800°	200°
Steam . .	1,000°	600°	400°
Air . . .	1,000°	400°	600°

Thus, a given area of plate surface, after it has received its own *status* of temperature, will transmit the entire 1,000 degrees it had received, *if the recipient be water.* If, however, it be *steam,* 600° only will be taken from it, the remainder, 400°, necessarily *remaining in the plate, there to accnmulate and increase in temperature,* in proportion to the intensity of the flame.

So, if the recipient be *air,* 400° only will be taken from the plate, leaving 800° to accumulate. From this we learn how the absorbing faculty of the recipient regulates and controls the transmitting action and temperature of the plate, and the extent to which it will be exposed of being unduly heated. The want, then, of free and adequate means of circulation of the water, and an unobstructed access to the plate, so that it may, at all times, be the recipient, may be taken as the chief, if not the only cause of their deterioration *through over-haetnig;* and wholly irrespective of thickness, or the degree of heat to which it may be exposed. The temperature and durability of the plate will, therefore, be in the *inverse ratio of the rapidity of the current* of heat passing through it, while such transmitting current will be in the *direct ratio of the absorbing power* of the recipient, whether it be water, steam, or air, or a mixture of either.

CHAPTER XIII.

OF THE DRAUGHT.

THE Draught, or current of air passing through a furnace, is occasioned by the difference in weight between the column of air within the chimney, and that of an external column of the same proportions,—the "ascent of the internal heated air," as Dr. Ure observes, "depending on the diminution of its specific gravity,—the amount of unbalanced weight being the effective cause of the draught." Since, then, this levity of the inside air is the result of increased temperature, the question here for consideration is, how that temperature may be obtained with the least expenditure of fuel.

In marine boilers numerous cases of deficiency of draught will be found to arise from an injudicious arrangement of the flues, and the conflicting currents of the heated products within them.

Notwithstanding the importance of the subject, still but little attention has been given to the causes of these currents and deficient draught. M. Peclet having examined the subject with great care and practical research, his details are so copious, and his remarks so much to the point, that it will be well to give them due attention, and the more so as the subject has not hitherto been examined by any writer in England.

Among the inconveniences experienced, a prominent one may here be mentioned, as being of frequent occurrence, namely, a deficient draught in the side or *wing furnaces* of boilers.

M. Peclet observes, "Where several tubes or flues open into one common flue, the currents are continued beyond their orifices, and by their mutual action, affect or modify their respective forces. If, for example, two flues, A and B, (see Fig. 100) enter the common flue C, by orifices *opposite each other*, the influence of their currents on each other will be *nil, if they have equal rapidity;* because the whole will pass as if they had struck against a plane fixed between them. If, however, the currents be unequal, *that which has the greatest rapidity will reduce the speed of the other*, and more or less have the effect of closing the orifice through which the latter flowed."

Fig. 100.

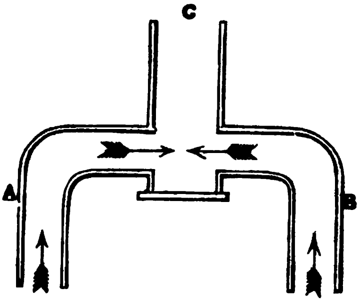
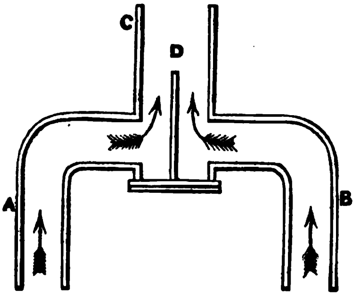


Fig. 101.



"So many proofs of this," he adds, "may be adduced, as to put the fact beyond doubt." "These streams of air," he continues, "in this respect, act on each other as streams of water. It is already known by the experiments of *Savart*, that where two streams of water, of the same sectional area, act in opposite directions, and that one of them has even but a little more speed than the other, the latter is pushed back, and the influence felt up to its source. The result of this collision in the flue may be avoided by the Diaphragm D (Fig. 101)." Such conflicting currents may be found in almost all marine boilers, yet pass unnoticed, even where the draught is manifestly deficient in consequence.

Again, "Phenomena of the same kind will be produced where the courses of two flues are at *right angles to each other*, as in Fig. 102. These effects may also be avoided by the Diaphragm D (Fig. 103)." This also is of frequent occurrence, and seriously affects the general draught, as will hereafter be shewn.

Fig. 102.

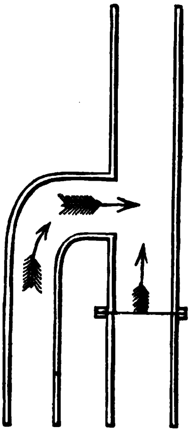
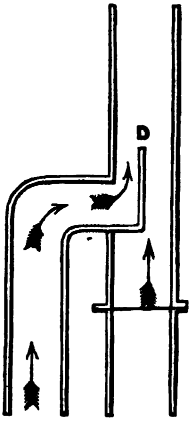
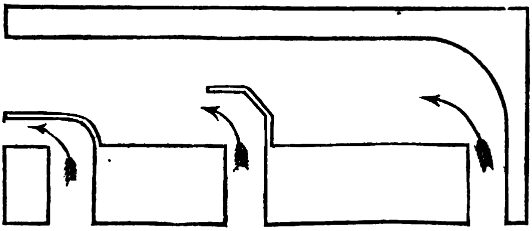


Fig. 103.



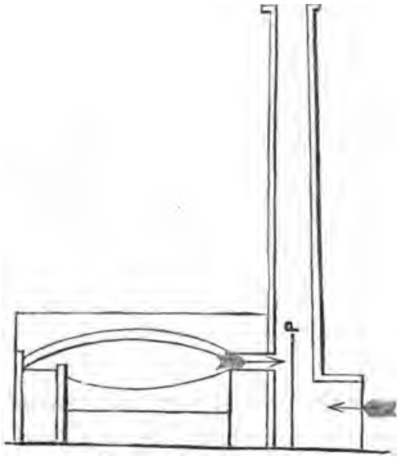
Again, " Where the chimney or flue is common to several furnaces, the arrangement should be such that the streams, or currents, of heated gas, should not interfere with each other. Fig. 104 represents the arrangement that should be adopted in such cases." It is needless to observe how frequent this state of things occurs, and how little attention is given to it.

Fig. 104.



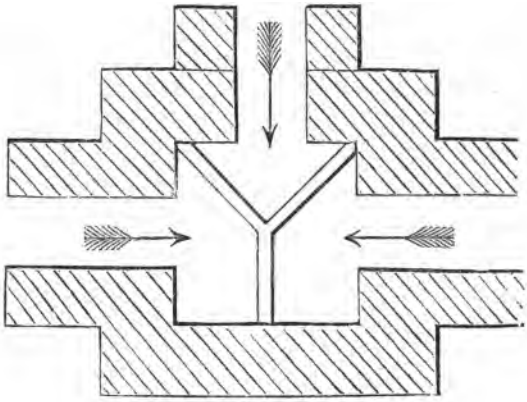
"So, where a current of hot products issues horizontally into a chimney, it may happen that its draught would be *entirely destroyed,* if the rapidity of such current was considerable, as it would then have the effect of shutting the chimney like a damper." He then describes what occurred at a soda manufactory, with a chimney for general draught, which he had to construct, and which was also connected with a flue from another apparatus, as shewn in Fig. 105. In this case, "the current from the one flue completely neutralized that of the other." This he remedied by the partition P.

Fig. 105.



Again, where three flues enter a funnel from *three different points*, it is evident, he observes, that "the diaphragms should be so placed as to leave each current an adequate section of the chimney," as in Fig. 106. The circumstance here referred to may be found to exist in almost all marine boilers. Rarely, however, is the interposition of these diaphragms thought of, yet numerous instances of the derangement of the draught, particularly of the wing boilers, must be within the knowledge of all engineers.

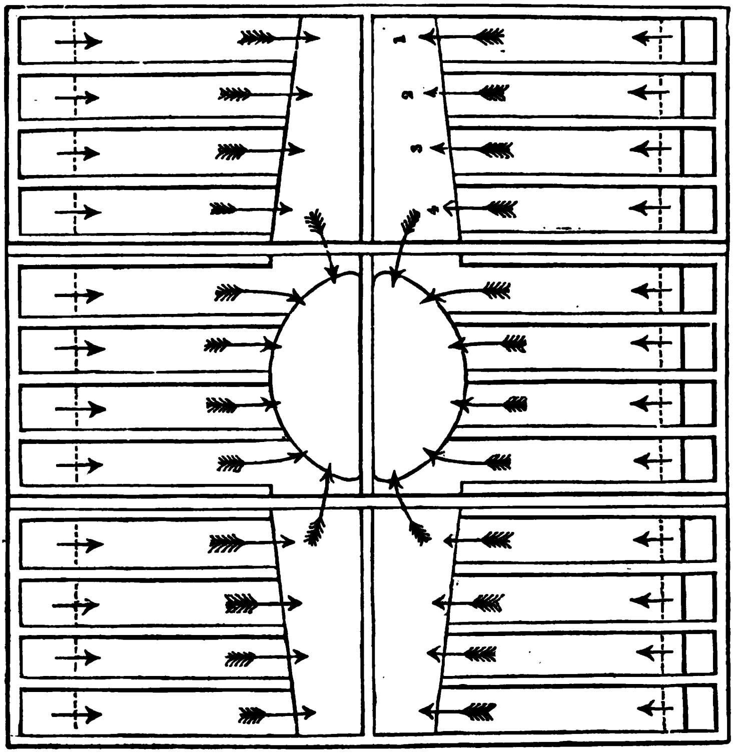
Fig. 106.



Let us now apply these judicious practical observations. The first boilers of the "*Great Britain,*" screw steamer, are in point. The arrangements of these boilers have already been noticed with reference to their impeding the due *circulation of the water.* We have now to consider them in respect to their influence on *the draught.*

In these boilers, attention was given, almost exclusively, to two objects:—providing the largest possible amount of *fire-grate areas*, and the largest aggregate of internal *heating surface.* As to the former, almost the entire area of these large boilers may be compared to an aggregate of furnaces. Nevertheless, there was no command of steam, and the engineer stated, that the wing boilers were unequal in draught to the centre ones. The deficiency of draught in the furnaces of the side boilers will easily be accounted for on examining the plan of the upper tier of flues, and the numerous collisions where the heated products from twenty-four large furnaces entered the funnels, as shewn in Fig. 107.

Fig. 107.



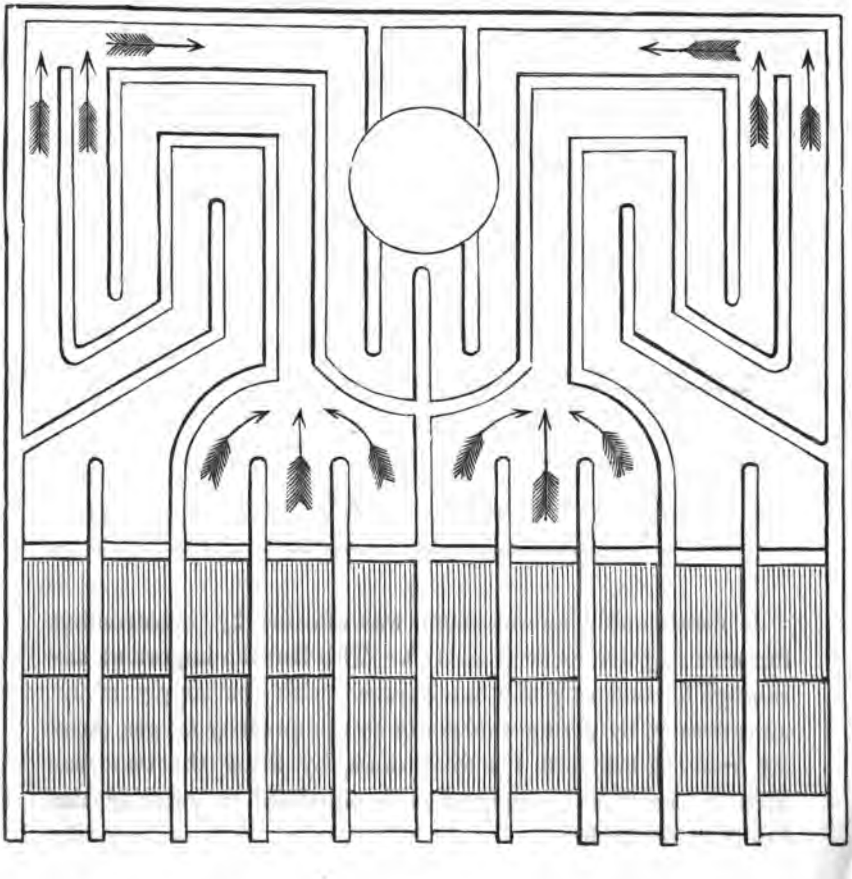
The flues from the four furnaces of each wing boiler, are here made to enter one common cross flue—each thwarting the current of the preceding one. No. 1 being checked by No. 2—which crosses it at right angles—which, in its turn, was checked by No. 3, and so on—the same mal-arrangement taking place in each of the sixteen flues of the four wing boilers. These, it will be seen, are the direct cases adduced by M. Peclet, where the products and current from one flue act as a damper on the *draught of its preceding one.*

Again, the joint products of the four flues of each wing boiler are made to enter the funnel by a single opening, which is not only at *right angles* with the flues from the four centre boilers, but *directly opposite to those of the wing boilers* on the other side.

Thus the flues of no less than eight furnaces, all entering by a single opening, are brought into direct collision with those of the other four, and in the most certain way to affect the draught of all. Here we have a combination of the evils referred to by M. Peclet.

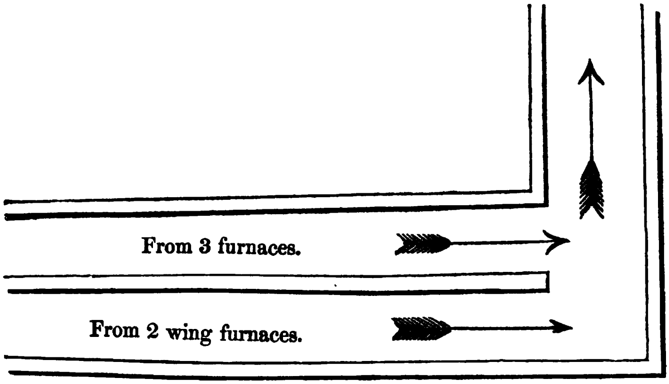
The case of the boilers of the "*Great Liverpool*," is a still greater violation of the rules which should regulate the draught. Here, there being but a single tier of flues, the required aggregate of *heating internal surface* was obtained by the labyrinth of windings shewn in Fig. 108.

Fig. 108.



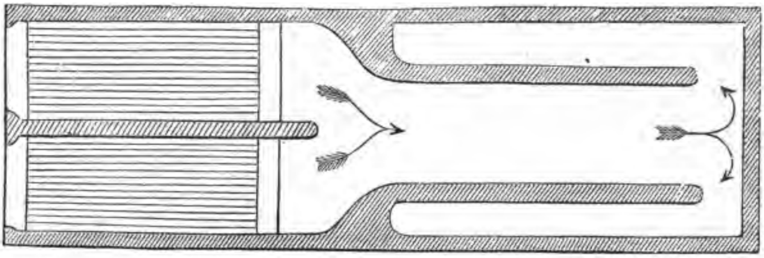
In the first place, the flames from the three centre furnaces of each half of the boiler are forced into a single flue of but 13¾ inches wide, as shewn by the arrows. Again, the gaseous products of each set of three centre furnaces, and which are necessarily the more powerful, are made to enter the single back flue at *right angles,* and across the current of products from the two wing furnaces, as shewn by the enlarged view in Fig. 109. It is scarcely possible to conceive a more direct case of collision, or a more effectual damper by the hotter and larger current from three furnaces, on the smaller current from the two wing furnaces. In these boilers, it is manifest that nine-tenths of the steam was produced by the plates in connection with *the furnaces alone,* and by a system of continued forcing; the long run of flues being filled with dense black smoke.

Fig. 109.



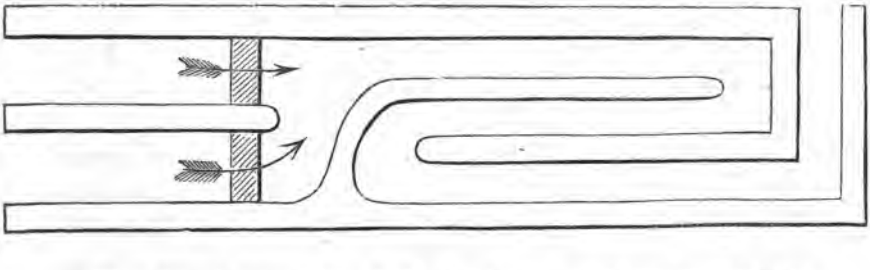
A considerable improvement was effected by constructing furnaces *in pairs,* as in Fig. 110. This had the important advantage of rendering any interference with the supply of air unnecessary, by giving uniformity to the quantity of gas passing from the bridge to the flue; since, by firing the two furnaces *alternately,* the supply of gas is equalized on entering the flue from the bridges.

Fig. 110.



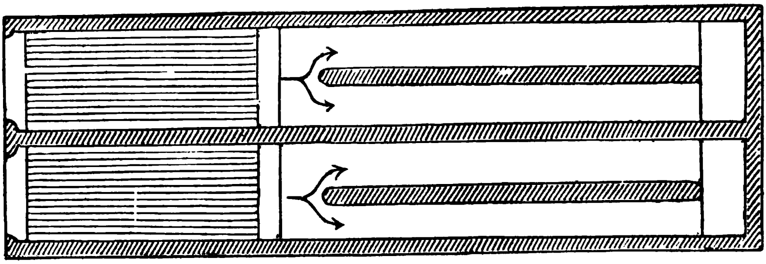
This plan, it will be seen, had the disadvantage of *the split flue* at the back end, where, as M. Peclet observes, *the hotter or stronger current will always neutralize the other.* In practice, a strong or hot current of gaseous products will not, voluntarily, divide itself, to meet the arrangements of the flues: the whole, or nearly so, will pass either to the one or the other, in proportion to the temperature then in the flue, or to the length of the course each has to run to the funnel.

Fig. 111.



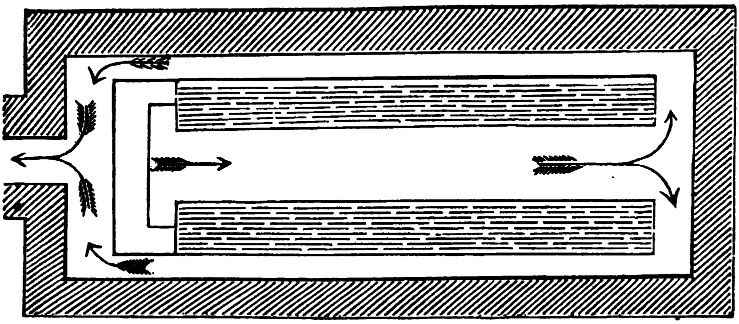
The plan shewn at Fig. 111 exhibited a great improvement in the former, and has for many years been found the most efficient in practice.

Fig. 112.



The plan, as in Fig. 112, was adopted with the view of dividing the gaseous products, and thus spreading the heat along a double surface. This, however, was quite defective, in as much as a gaseous stream cannot be induced to divide itself contrary to the laws governing the currents of fluids; the hottest and shortest course being always taken by the gaseous products.

Fig. 113.



The plan of a land boiler, as in Fig. 113, is that of a still more objectionable effort to divide the current into two smaller flues, with the view of increasing the internal surface. Here, the flue, after passing under the cylindrical boiler, and returning through a central flue, is expected to divide itself into two streams, one to pass on each side of the boiler, on their way to the chimney. This is the case referred to by M. Peclet. A commission, he observes, from the *Société Industrielle* of the Grand Duchy of Hesse, made a series of experiments to determine the influence of the circulation of the products of combustion round boilers. By these it was proved, that the flue passing round the boiler had a considerable effect on the amount of evaporation. It was also established, that if the products pass simultaneously by the two side flues, they will *not distribute themselves equally, and will only pass by that which presents the least resistance.*[*]

On the *external* circumstances that influence the draught, M. Peclet adduces many proofs of the importance of avoiding any interference with the introduction of the air, by reason of the *direction of the wind outside the building*. This is a circumstance which has excited no attention from our engineers. In marine boilers, placed low down in the vessel, the direction of the wind, with reference to that of the current entering the furnace, has often a considerable effect on the efficiency of the combustion. So, if the wind is opposed to the motion of the vessel or the reverse. The importance of this consideration is exemplified where the vessel contains two boilers, having their furnaces facing different ways. In such case, according to the direction of the wind, or the motion of the vessel, one boiler will have a better draught than the other.

That the relative direction of the wind, and the vessel, exercises a considerable influence, is proved by the fact, that the furnaces in some vessels will have a sufficient draught, and generate a sufficiency of steam, when going *head to wind*, but be deficient in draught when going *before the wind*. These circumstances merit more attention than is given to them. We hear of the relative merits of two steamers on a trial of speed being determined, by a slight advance of the one compared with the other;—the superiority of the former being perhaps attributed to the form of the vessel; the true cause, however, often depending on the *better command of draught*, and, necessarily, a better command of steam, by which the one was enabled to make a revolution of the wheels, or screw, more than its rival. In a late discussion at the Society of Arts, on the subject of the prevention of smoke, Mr. D. K. Clark "testified to the advantage of a rapid, or rather, intense draught, in perfecting combustion and extinguishing smoke." "This," he observed, "was the panacea he constantly held forth for the universal prevention of smoke in large furnaces." Mr. Clark's views are, unquestionably, well founded; but the practical difficulty lies in the obtaining this "intense draught," or an adequacy of draught for even imperfect combustion, in many marine boilers.

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[*] "The hot air, after having passed through the lower part of the boiler, returns to the front by a centre flue, and passes to the chimney simultaneously by two side flues. By this arrangement, the heating surfaces are more available, but it is difficult to divide equally the hot air into the two side flues. Almost always the current is greater in one than in the other, and the hot air will pass *but through one of them*. In that case it will be necessary to have registers at the end of each."

The absolute *command of draught* for the generation of the required quantity of steam, to enable the engines to work to their full power being then so essential, it becomes a question whether *other means than the natural draught* should not be resorted to; since, independently of the uncertainty in the amount of draught, and the consequent irregularity in the working effect of the engines, the cost of sustaining that draught may be so much in excess of what an *artificial draught* would be.

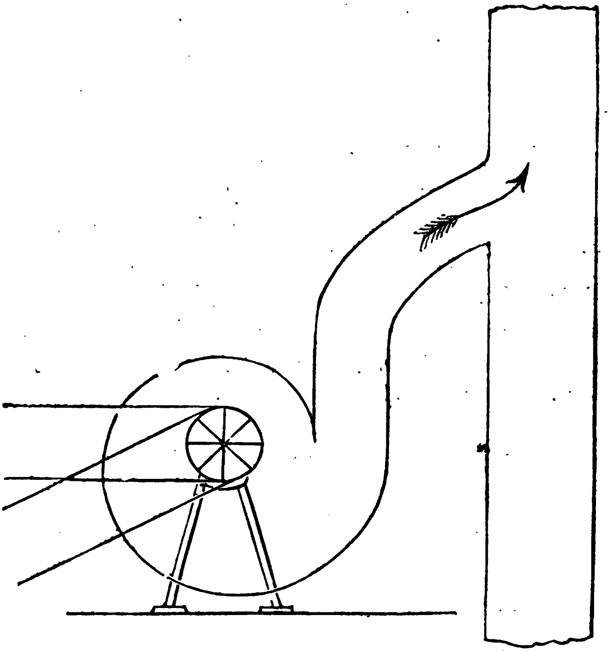
This branch of the subject has excited little attention in this country. M. Peclet has investigated it with his usual care, and his results are worthy of record. "Where the draught," he observes, "is created by the expenditure of fuel and heat, *the expense exceeds one fourth of the combustible used.* If we have not the means of otherwise employing that heat, the natural draught, by the chimney, is then admissible. If, however, that heat may be made available for the purposes of evaporation, and if a draught, *mechanically obtained*, would cost less, it would then be more advantageous to use it."

Among other proofs, he gives two instances which establish the fact. One, the hot baths on the Seine at Paris the result of which was, that what was effected by the labour of one man alone, when the draught was *mechanically* produced, cost the value of seventeen men's labour when produced by the *natural draught* from the heat of the furnace.

The second case was that of a large brewery, where the power employed was that of 200 horses. In this instance, *a ventilator which employed the power of but six horses, was sufficient to produce a draught equal to that of 50 horses, obtained by means of the natural draught of the chimney.*[*]

He then proceeds to consider the relative merits of the several descriptions of ventilators; and comes to the conclusion, that the rotary fan with plain wings, but with the excentric motion, is to be preferred. The mode recommended for its application is given in Fig. 114, where, by means of *an exhausting fan*, the heated products were directed into the ordinary chimney shaft.

Fig. 114.



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[*] Mr. Prideaux, in his rudimentary treatise, observes, "However compatible with the objects sought to be attained may be the plan of keeping up the draught through a fire, by the instrumentality of a chimney, where *slow* combustion only is required, as in the case of a domestic grate, or the Cornish boiler: whenever, on the contrary, rapid combustion and intense heat are a

This opens a new field of inquiry, and which is far more important than any question arising from the mere relative cost of the *natural* or *mechanical* draught, the best constructed boilers not unfrequently being insufficient, from the mere circumstance of a deficient draught.

Impressed with the importance of the subject, several experiments by means of a fan apparatus, worked by a small steam engine, were then made. The arrangement, as described in Fig. 115, also afforded the means of deciding many important points connected with the length of run,—the working temperature in the flue, and that of the escaping products at the chimney. In this Fig. A represents the boiler, 15 feet long, with an upper returning flue, having its own chimney A′ furnished with a thermometer C, and a damper D, Houldsworth's pyrometer P, being connected with the return flue farthest from the furnace. Two sight apertures were introduced,—the one at S, opposite the furnace, to observe the action of the air, introduced through the door and air-box above it, as already described; the other S′ looking into the upper flue.

To test the practicability of converting the great heat which escaped by the chimney, an auxiliary boiler B was attached, by means of a continuation flue E, and furnished with a separate chimney B, with an exhausting fan F, to produce an increased draught. This auxiliary boiler had two thermometers, to ascertain the temperature of the escaping products, C′ and C″, and a damper D′, so that the two boilers might be used separately or conjointly.

desideratum, such a system can only be carried out by an enormous waste of fuel. I shall, no doubt, excite general surprise, and perhaps some incredulity, when I state that, from a calculation I entered into on the subject, I find that 1 lb. of coal, expended through the mechanical agency of a steam engine, will generate more force, and, consequently, is capable of producing a stronger current of air, than 500 lbs. of coal expended in heating a column of air, to act by its diminished specific gravity through a chimney 35 feet high."

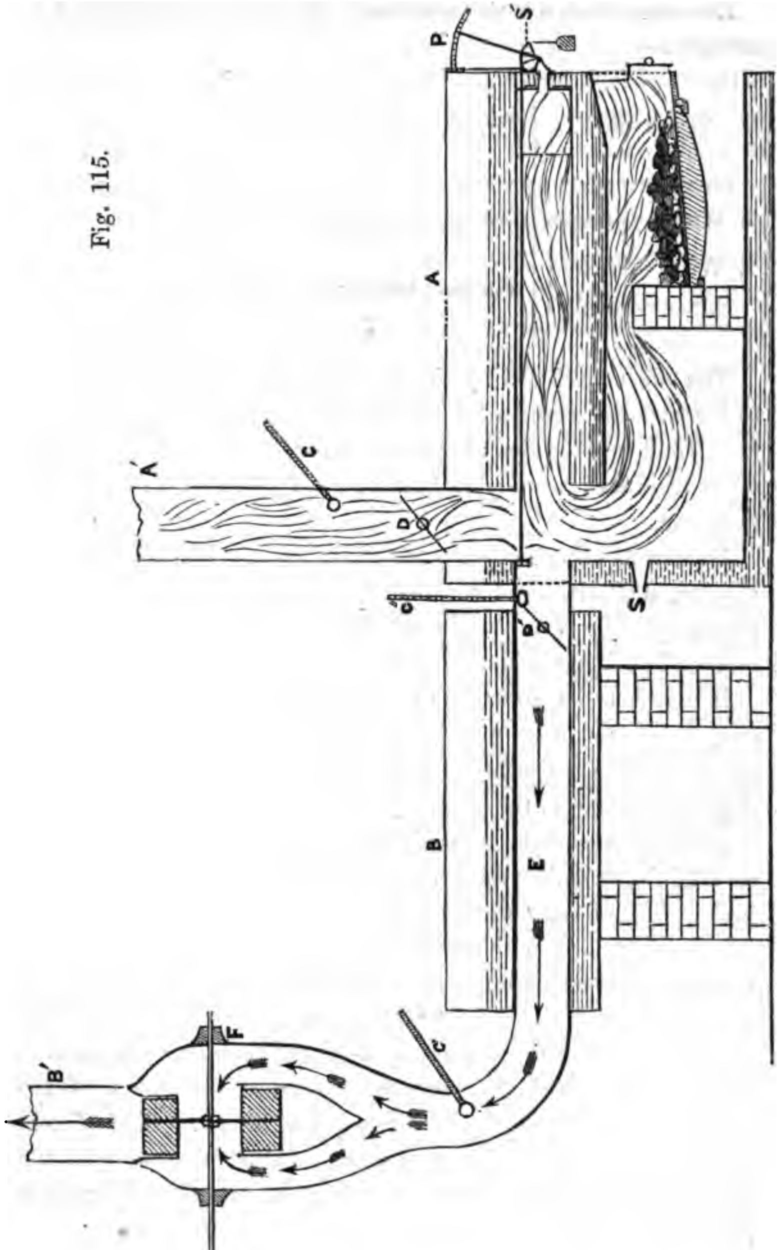

Fig. 115.

Experiments with the auxiliary boiler and exhausting fan draught:—

Experiments.	Coal used per hour.	Water evaporated per hour.	Water evaporated per lb. of Coal.	Pyrometer heat in flue.	Temperature of heat escaping.
1. With fan draught	265 lbs.	2454 lbs.	9·26 lbs.	1025°	650°
2. With ordinary chimney draught	215 lbs.	1552 lbs.	7·21 lbs.	725°	410°

The effect produced by the fan draught was thus not only to increase the evaporative power of the boiler, *within the hour*, from 1552 to 2454 lbs. of water, but to increase the evaporative effect from *each pound of coal used*, from 7·21 to 9·26 lbs. within the hour.

Numerous other experiments were made with and without the fan, and with and without the auxiliary boiler: all confirmatory of the value of the artificial draught, and of the increased lineal run of flue.

It may here be observed, that experiments on heating and evaporating must be utterly useless, unless due attention be given by the experimenter to what has hitherto been so neglected, namely, the quantity of heat escaping by the chimney; the extent of the transmitting power of the boiler; and the ascertaining whether the process of combustion had been complete. The above described apparatus supplies the means of ascertaining, and with great accuracy,—1st, the evaporative value of different descriptions of coal or coke; 2nd, the effect of greater or less lineal run; 3rd, the temperature in the working flue, indicative of the amount of heat produced throughout each charge of fuel; 4th, the length, character, and colour of the flame; 5th, the quantity of air required by each kind of coal or coke, and the most effective way of introducing it; 6th, the weight of water evaporated in any given time, and by each pound weight of fuel.*

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* I have given the above details, as they indicate what are the essentials in

In proof of the utter uselessness of experiments, unless accompanied by such data, may be mentioned the elaborate paper presented to the Society of Arts for Scotland. In the details of the several experiments, the distinctions here drawn were wholly overlooked. The result was, the learned experimenter was led to results and inferences altogether erroneous.

His paper was "On the evaporative powers of different kinds of Coal;" but, neglecting to take account of the quantities of heat or heating matter carried away or lost, and the quantity of gas escaping unconsumed, or converted into smoke, he came to the conclusion that, "the evaporative power of each kind of fuel is in *the exact ratio of the fixed carbon contained in each.*" It is needless to say, that such an inference is entirely disproved by modern practice.

A few words here may be said on the subject of *quick and slow combustion,* as being connected with that of draught. The impression that a process of slow combustion is more economic than a quick process, has arisen from the fact, that a given weight of coal will convert a greater weight of water into steam under the former than the latter. Were the sole object the obtaining the largest measure of heat from a given weight of fuel, as, for instance, in heating an apartment by means of Dr. Arnott's stove—in such case slow combustion would be attended with the greatest economy. In the use of coal, however, for the supply of steam to an engine, the question is of an essentially different character. It would thus be, not how many pounds weight of water may be evaporated by each pound of fuel, but how many pounds of water can be converted into steam by *the smallest quantity of fuel within an hour, or any given time. Time* is, in fact, the test of efficiency. The following experiments will illustrate the merits of the two systems.

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all boilers constructed for experimental purposes. So accurate were the results when tested by the eye, the pyrometer, and the thermometer, that it has for many years been the custom of coal owners to ascertain by this boiler the effective value of each description of coal; themselves, or their agents, superintending the operation.

	Coals burnt per hour. lbs.	Water evaporated per hour. lbs.	Water evaporated per lb. of coal. lbs.
Slow Combustion	84	787	9.37
Quick Combustion	224	1362	6.08

Now, if no more steam was required for the engine than would be produced from 787 lbs. of water *within the hour*, *slow* combustion would be the most economic. If, however, the engine required the steam of 1362 lbs. of water per hour to work to its full and required power, then *quick* combustion would be the most desirable, as being the most efficient.

Suppose, for instance, a steam ship required that the wheels should make 20 revolutions per minute, and that, to produce such, the engines required the steam of 1362 lbs. of water *per hour*, what compensation for the consequent loss of speed would it be, that although the wheel made but 12 revolutions per minute, yet *economy of fuel* was secured, in as much as each pound of coal did more duty, in the ratio of 9.37 to 6.08.

Thus, it is evident, that *economy* and *efficiency* may be antagonistic,—economy of fuel being waste of time, and waste of time being waste of power. In practice, then, and with marine or locomotive boilers, it may be taken as established, that *rapid* combustion is more economic of *time*, and *slow* combustion of *fuel*.

CHAPTER XIV.

OF THE TUBULAR SYSTEM AS APPLIED TO MARINE, LAND, AND LOCOMOTIVE BOILERS, IN REFERENCE TO THE CIRCULATION OF THE WATER AND THE PROCESS OF COMBUSTION.

HAVING considered these subjects in reference to *flue* boilers, we have now to examine them in connection with the *tubular* system. The annexed views of a locomotive and a tubular boiler will enable us to appreciate their respective peculiarities.

In the locomotive, Fig. 116, the furnace compartment (called the fire-box) is placed at one end of a long boiler, and so apart from the tubular compartment, that, as regards the objects of circulation and evaporation, they may be considered in the light of separate boilers.

Fig. 116.

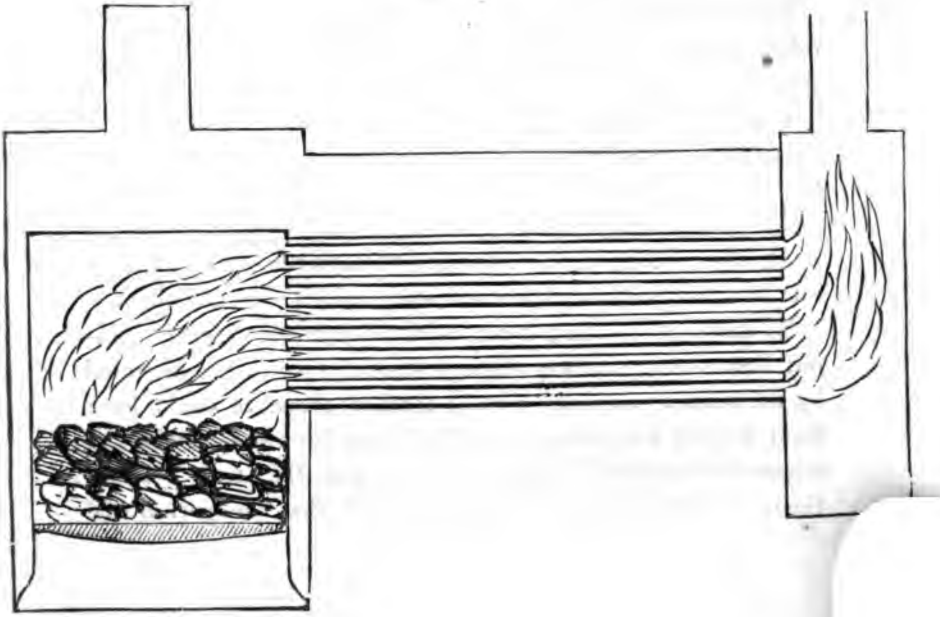
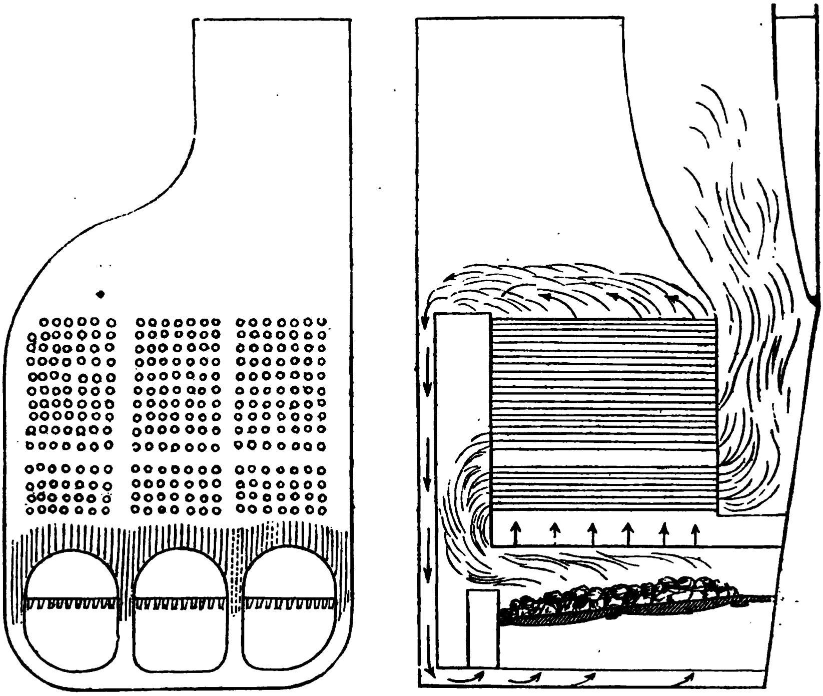


Fig. 117.



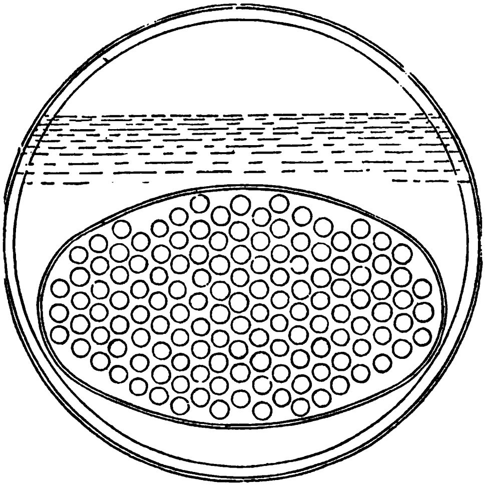
In the marine boilers, as in Fig. 117, on the contrary, the tubes, placed directly over the furnaces, become enveloped in the atmosphere of steam generated, and rising from the latter. This is virtually the placing one boiler over another;—a tubular over a flue boiler, and within the same shell. By this arrangement, the steam generated from the furnace department (and which is necessarily the largest in quantity) cannot reach the surface without passing through the numerous close sets of tubes, and the steam and water which surround them.

So also of the water; it can neither ascend or descend without first working its way through the intricate mazes presented by the tubes:—no more certain method therefore could have been devised for producing a mischievous interference with the respective functions, both of the water and the steam. Here, then, is another violation of the principle, that "no part of the heating surface should be so situated that the steam may not readily rise from it, and escape to the surface of the water."

Duly to appreciate these obstructions, let the inquirer only ask, what direction it was intended the steam should take on rising from the sides and crown plate of the furnace; or the water in its ascending and descending currents? On such an inquiry it will probably be found that the projector had never considered the circulation or currents of either steam or water, or even thought such an inquiry necessary.

So little, indeed, has the "free escape of the steam to the surface," or the currents in the water, been thought of, that we not unfrequently find the congeries of tubes arranged, not in *vertical lines*, but so *alternated* that each directly intercepts the currents both of the steam and water rising from that below it, as shewn in Fig. 118; as if it had been expressly *intended to obstruct circulation* rather than promote it, and keep the tubes continually enveloped in *steam* rather than *water*;—both having to run the gauntlet through a zig-zag course of narrow and intricate passages.

Fig. 118.

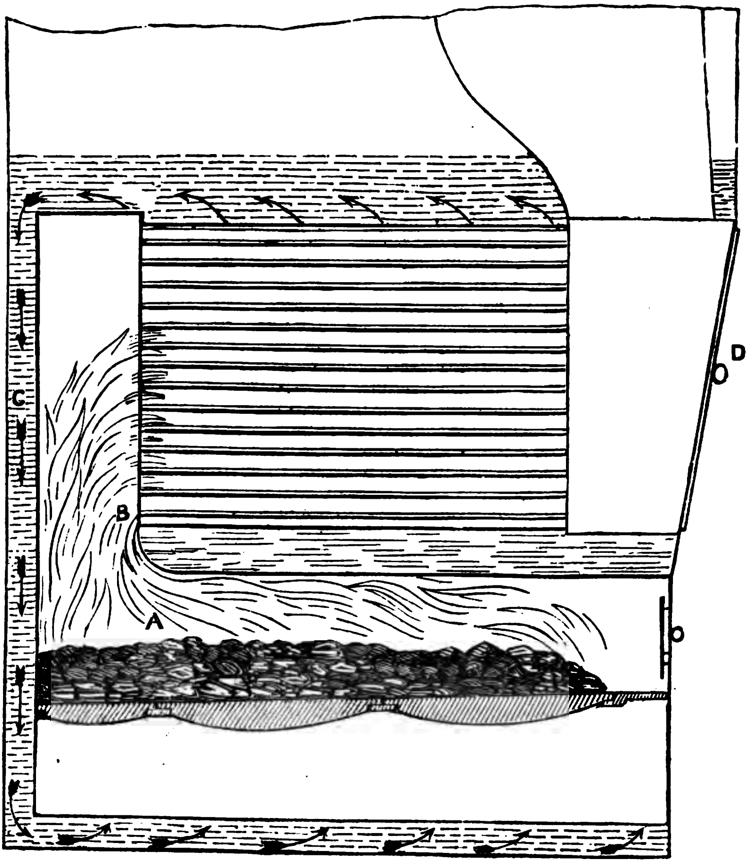


Dr. Ure observes, that "as the diffusion of heat through a fluid mass is accomplished by the *intestine currents*, whatever obstructs these currents must obstruct the changes of temperature." Yet it would be difficult to contrive a more effectual mode of obstructing the intestine currents of both steam and water.

In proceeding to consider the marine tubular boiler, it will be well to take one of modern construction, and examine how far its arrangements are in accordance with the operations of nature, and particularly as to the following points, viz.:—

1st. The proportions of the furnace.
2nd. The distance the flame and heat have to travel.
3rd. The time available for giving out heat.
4th. The admission of the air.
5th. The circulation of the steam and water.
6th. The effects of the tubes, as heating surfaces.
7th. The economy.

Fig. 119.



First.—*Of the proportions of the furnaces.* A remarkable feature of this boiler is, that its entire area may be considered as one large furnace, indicating the dependence on this department for the supply of steam. As to its several parts, there is disproportion everywhere. The chamber above the fuel is not one-half the size it should be in proportion to its length. Allowing a proper body of fuel on the bars, there will not be 12 inches space between it and the crown plates; yet in this shallow chamber, and under the influence of a rapid current through it, all the operations of gas making, gas heating, mixing with the air, and combustion, are to be carried on. On this head Mr. Murray justly observes,* "As a large furnace is found by experience greatly to facilitate the admixture of the gases, and to ensure their more perfect combustion, as well as to afford the most effective kind of heating surface, it is of great importance that there should be *plenty of room over the fires.*" It need only be observed, that in this boiler we have the very opposite of this recommendation; there being, in fact, the least possible "*room over the fires.*"

So of the ash-pit; although above 9 feet long, it has but an average depth of 18 inches. Thus the spaces, both above and below the fuel, have the character of long narrow passages, causing injudicious longitudinal currents, and counteracting all the processes of nature.

Second.—Of *the distance* which the flame and heat have to travel. The deficiency is here remarkable, there being, in fact, but a few inches of *lineal run* between the fuel and the first range of the tubes; say from A to B. It may then be asked, what is to become of the great body of flame and half-burned gases rising from the coal on an area of 20 square feet, the bars of each furnace being 2 feet 6 inches wide, by 8 feet in length; the six furnaces of each boiler thus presenting an aggregate bar surface of 120 square feet.

Now the disposing profitably of this mass of flame is the really important question. If left to itself, and duly supplied with air, it would have extended to a distance of 15 to 20 feet from the bridge, along which course it would continue profitably giving out heat, and producing evaporation. All this capability is, however, here sacrificed, since, as already shewn, flame cannot pass unimpaired, or unextinguished, through a series of metallic tubes, and without being so affected by that subdivision which weakens and destroys intensity.

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* *Rudimentary Treatise on the Marine Engine:* by Robert Murray, C.E. Weale.

The management of flame is, we have seen, at all times an extremely delicate and difficult operation; here, however, all the processes of nature are deranged. Here is the largest volume of gas and flame, concurrently with the least provision for the admission of air for its combustion;—the greatest quantity and intensity of heat in the furnaces, with the shortest run, and the least fraction of time for imparting that heat to the plate surface. Instead of being allowed to pursue its course, and have due time for the combustion of its carbon, the flame is here suddenly and mechanically divided into 360 small portions, by being forced into that number of tubes.

It has already been shewn, that it is essential to the existence of flame, that its *high temperature be sustained, until the process of combustion be completed;* yet the most effectual means of reducing its temperature, as shewn by Sir H. Davy, is to *break it up* (as is here done) into *numerous feeble portions.* The result is, that the carbon of the gas, (then in the state of flame,) instead of being converted into carbonic acid, and producing a very high temperature, is, by these cooling influences, reduced below that of ignition, and then consequently deposited in the form of dense smoke and soot. The boiler now before us produces unvarying columns of smoke of the blackest character. So great, indeed, is the quantity of deposited carbon, that the tubes are not unfrequently entirely filled, and would remain permanently choked, were it not that the fuel, becoming alternately incandescent, and the bars irregularly covered, much air then passes, and relieves the tubes of the deposited carbon; filling the atmosphere and covering the decks with masses of "blacks."

Next to the *admission of the air*, the *length of the run* is the most important element of efficiency in the working of a furnace. Where short tubular boilers are employed in steam vessels, the only alternative for avoiding the waste by smoke is the use of *anthracite coal;* and which, as it contains but little of the hydro-carbon gases, comes nearest to the use of coke in the locomotive.*

With reference to the shortness, or rather absence, of run in this boiler, and looking to the great body of flame produced, it may be regarded as rather a fortunate circumstance, that these masses of tubes are thus interposed, as they become the direct means of cutting short the flame and intense heat, and thus prevent it from passing to the take-up and funnel, and keeping them at the dangerous temperature of redness.

The inference is, that the tubular boiler (accompanied by a short run, with a large area of fire-grate, and using bituminous coal,) is wholly incompatible, not only with perfect combustion, and obtaining the due measure of heat from the fuel and flame, but even with safety, unless under the influence of some such protection, or preventive, as these tubes supply, and which as effectually extinguish the flame as the patent *fire annihilator* does, at the moment its continuance would be productive of danger. This is indeed a costly and complicated mode of protecting the funnel and up-take. Nevertheless, it has that effect, though a very different one from that which had been contemplated.

As illustrative of the want of system in this matter, it may be mentioned that a land-engine boiler was made at the same time, on the ordinary flue principle, but in direct opposition to that of this tubular;—the *land-boiler* having a very long run—the marine-boiler having scarcely any. In the former, the flue, after passing under the boiler, the entire length of 30 feet, was led round it to the chimney, thus giving a run of 100 feet lineal. By this means not only surface, but distance and time were secured for obtaining heat from the gaseous products, and transmitting it to the water. In this *marine*-boiler, on the contrary, by means of the short run, both distance and time are sacrificed, and consequently heating power lost. It would be difficult, therefore, to reconcile the principles on which these two boilers were constructed, seeing that their arrangements were in such direct opposition to each other. Either the one or the other must have been altogether erroneous.

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* The owners of the *Great Britain*, with tubular boilers, have been compelled to adopt this description of coal; 1000 tons of it being put on board for each voyage. The boilers in this vessel are on the close tubular principle.

Third.—*Of the time* allowed for giving out heat. *The question of time and distance* being so directly connected, whatever influences the one must have a corresponding effect on the other. When, however, we consider that the time or interval that can elapse between the passing the flame from the furnace, and its reaching the tubes, can be but a *small fraction of a second,* such must be wholly insufficient for giving out the heat from so enormous a body of flame. In this respect, then, the marine tubular boiler is pre-eminently defective. The consequence is, that the generation of steam is almost exclusively confined to the region of the furnace, and the direct radiated heat from the flame in them.

Fourth.—Of the *admission of air.* No provision whatever is here made, apart from that by the ash-pit. The manifest error of such an arrangement will be best understood by pointing to the utter impossibility of the 300,000 cubic feet of air required for the gas, together with the 600,000 cubic feet for the coke from the *three tons of coal hourly consumed* on the bars, to find access through the body of coal resting on them.

Fifth.—Of the *circulation of the water.* In this boiler nothing has been done in aid of the circulation, but much, on the contrary, to embarrass both its ascending and descending currents. This is even aggravated by the circumstance of the water-space, at the back end, which in *flue boilers,* as being the *coldest,* and farthest from the furnaces, and most *favorable for the descending water, is here the hottest;* the great body of flame being projected directly against it at C, and therefore most unfavorable for that descending current.

Sixth.—Of *the tubes, as heating surface.* The value of the tubes, in a *locomotive,* arises from their presenting a larger aggregate of internal heating surface for contact with the heated gaseous products—these being chiefly transparent carbonic acid and oxide, and in all instances free from smoke or carbonaceous deposit. In the *marine tubular,* however, where coal is used, and no such transparent gaseous products exist, but on the contrary, where there must be always a large volume of fuliginous gas and flame, the tube system is wholly inapplicable.

In adopting the tubular principle in *marine boilers,* it was no doubt supposed that the increased surface would have been equally effective and unobjectionable as in the locomotive. This inference was drawn, however, without taking into account the chemical difference between the use of bituminous *coal,* in the one case, with its accompaniments of gas, flame, and smoke, and of *coke* alone, in the other, but in which none of these exist. Neither was it taken into account, that in the locomotive, the draught, and the all-essential volume of air introduced, was obtained by *artificial means,* and was therefore always sufficient and under control; whereas, in the marine-boiler, the required draught could only be obtained by a great expenditure of fuel and heat—in fact, by heating the funnel.

Seventh.—Of *economy.* In the use of *fuel* in this boiler, *economy is out of the question.* The great supply of steam being generated from the radiated heat and impact of the flame in the furnaces, the system of *forcing the fires becomes an absolute essential;* the greater the weight of coal consumed in given times, the greater being the amount of available flame produced.

As to *economy of space* in limiting the length of the boiler, we often deceive ourselves, since what is apparently saved is not all gained. Flue-boilers are comparatively low, admitting much of the coal supply to be placed over them. This may be done without inconvenience or risk; often, indeed, with comparative advantage, the coals so placed thus avoiding the accumulated deposit of the fine-powdered part, which takes place at the bottom of large bunkers when undisturbed, and from which that gas is generated which is so often found to ignite in spontaneous combustion. Tubular boilers, on the other hand, are necessarily high, extending to the deck. The consequence is that stowage for the coal must be provided elsewhere, by appropriating a portion of the hold to that purpose.

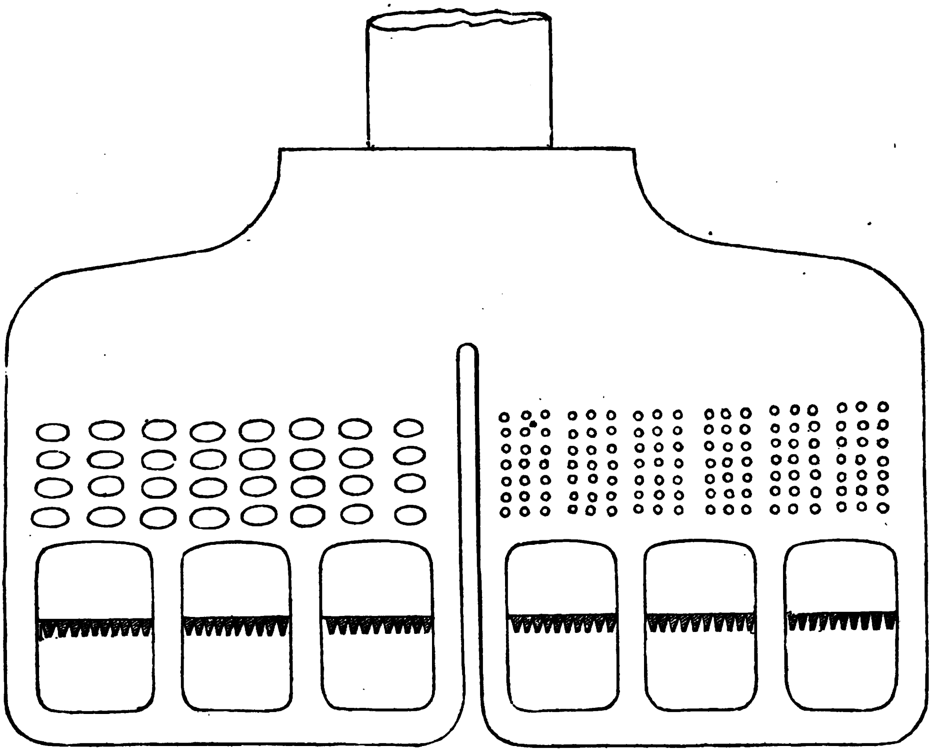
In the boiler now under consideration, the 360 tubes are placed in vertical ranges, 15 in each range. It is needless to repeat that the tubes, in ranges 6 feet in height, could not be available; since the lower ranges are the first occupied as being the hottest, with an accelerated current in proportion as their area is diminished.

A further disadvantage of the marine tubular boiler is, that there is no place for the deposit of soot, sand, ashes, and other matter which accompanies the use of coal; or the scale or sediment which is found both inside the tubes as well as outside of them, in the narrow water-spaces. The result is, that all this matter accumulates in the tubes and bottom of the smoke-box, requiring constant attention for its removal.

Again, to facilitate the removal and the clearing the tubes, the entire front of the boiler at D, instead of being *water-space*, as in flue-boilers, is occupied by a series of doors, 6 feet high, and which, as they are so liable to be over-heated and warped, admit much air, often igniting the unconsumed gas which has passed from the furnaces, and sending the flame to the up-take and funnel, keeping them at a dangerous temperature, as was the case in the steamer "*Amazon,*" over-heating these parts which were *under-deck,* and where no means of extinguishment was available.

A practical illustration of the disadvantages of small tubes, was afforded in the boiler of the steam-vessel, the "*Leeds,*" in which, for the express purpose of deciding the question, one-half the boiler was constructed with tubes of 3 inches diameter; the other having enlarged tubes of 7 by 5 inches, as shewn in Fig. 120.

Fig. 120



The result was, that for years no repairs whatever were required in the latter, while the former was a continued source of annoyance and expense; besides that, it was less effective as a steam generator. Many of the small tubes had to be renewed; the water spaces were liable to be filled with incrustation; and the face-plate, in which the tubes were inserted, required to be drawn in, and the tubes again riveted; innumerable patches and additional bolts were from time to time introduced to secure the back face-plate, and preserve it in its place.

Here also was a practical confirmation of the fact, that the mere circumstance of having a larger aggregate of surface had no effect in producing increased evaporation, the *aggregate surface of* *the small tubes*, in the one-half of the boiler, being *double that of the larger ones* in the other half.

An instance of the desire to obtain a large aggregate of internal surface, but without due consideration as to its being available or brought into operation, was shewn, in the late substitution, in a vessel of great magnitude, of a tubular for a flue boiler; a change, however, which was the reverse of being beneficial. This boiler, as represented in the annexed figures, was not less than 18 feet 6 inches high. This may be called a

Fig. 121.

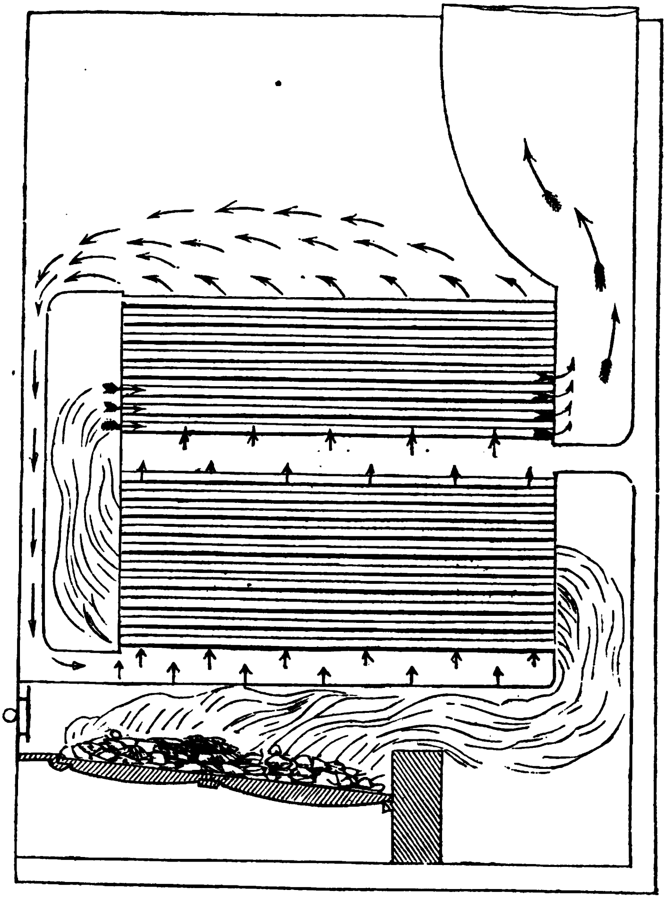
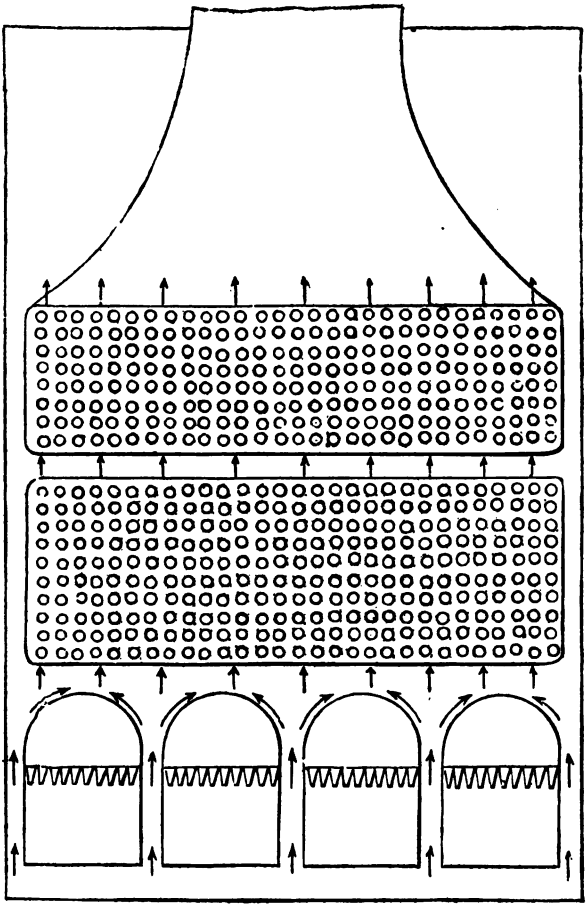


Fig. 122.



triple boiler—one flue, and two tubulars. Looking to the courses which the steam and water had to take in this boiler, it would be difficult to estimate the amount of obstructions which each would have to encounter, or the impediments interposed to their respective functions.

As to the general characteristics of marine tubular boilers, Mr. Murray, in his recapitulation, places them in strong contrast with what he considers the most important requisites, and which he enumerates as follows:

"1st. The boiler should be designed with a sufficient amount of heating surface, so contrived, that as little of it as possible may be rendered ineffective, either from the *retension of steam in contact with it* — from the formation of scales within — or from the deposition of ashes and soot in the bottoms of the flues and tubes." Now, the tubular system, *where coal is used*, is in direct opposition to all these conditions.

"2nd. The fire-bar surface should be sufficiently large to admit of the necessary quantity of coal being consumed with thin open fires." The policy of this condition, of thin open fires, may be correct, where the boilers are sufficiently large, and the consumption of fuel slow, as in the *Cornish boiler;* but is inapplicable in the *marine tubular*, which, by reason of the short run, and the necessity of throwing so much duty on the furnaces, involves the necessity of *hard firing and the forcing system.*

"3rd. That the proper area be maintained through the flues and tubes, and that the passage to the chimney be such that the draught be not interrupted." In the tubular boiler, the interposition of the mass of tubes is peculiarly instrumental in checking and interrupting the draught by their cooling and other influences, but without which, as already shewn, the funnel would be kept at a red heat.

"4th. That the *furnaces should be roomy*, and that the fires should not be larger than can be conveniently stoked." These conditions, as just shewn, are the very reverse of what exists in the marine tubular, more especially the first, enjoining a *roomy furnace.* The last head of this recapitulation is, however, as follows:

"5th. Which is, perhaps, the most important of all, and the one most neglected, that experienced and careful firemen be provided." Now, what the duties can be which demand such care and experience as to make this condition "the most important of all," is, however, not intimated, and never has been explained by any writer. It is, indeed, much to be feared, that the general insufficiency of boilers, caused by the absence of many of the truly important requisites, are too often laid to the account of careless or inexperienced firemen; yet, it may be taken for granted, that if any duties are required, beyond those of the very simplest character, and which can be taught any able and willing man in an hour, there must be some more serious mal-arrangement than can be remedied by any amount of care, skill, or experience on the part of the fireman.*

This is the more entitled to consideration, seeing, that in the above recapitulation, nothing is said of that which is really the most important requisite, namely, the provision for the admission of the air to the gas generated in the furnace chamber. Yet the great question of perfect or imperfect combustion involves the providing the relative volumes of air and gas. How strange, that with our present knowledge of the chemistry of combustion, so much stress should be laid on mere questions of proportions, while the main point, the *primum mobile*, is neglected.

On the inadequacy of the short boiler, short run, and short time for the performance of its several functions, Mr. Murray judiciously observes as follows: — "Superior economy of *large boilers*. Here arises a principle of economy, from the use of boilers of ample capacity to generate steam without the fires being unduly disturbed; and it is believed, that on this ground alone, can the alleged superiority of slow over rapid combustion, be maintained." There can be no doubt on the subject.

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* Where the air is properly introduced, the duties of firemen are all contained in the following instructions:—

1st. Begin to charge the furnace at the bridge end, and keep firing to within a few inches of the dead plate.

2nd. Never allow the fire to be so low, before a fresh charge is thrown in that there shall not be at least four to five inches deep of clear, incandescent fuel on the bars, and equally spread over the whole.

3rd. Keep the bars constantly and equally covered, particularly at the sides and bridge end, where the fuel burns away most rapidly.

4th. If the fuel burns unequally, or into holes, it must be levelled, and the vacant spaces filled.

5th. The large coals must be broken into pieces not bigger than a man's fist.

6thly. Where the ash-pit is shallow, it must be more frequently cleared out. A body of hot cinders overheat and burn the bars.

The true corrective then of these inconveniencies consists in letting the size of the boiler and its parts be commensurate with the demand for steam.

In illustration of the want of any fixed principle for the internal arrangements of the several parts of a boiler, it may be mentioned, that during the Parliamentary inquiry on the smoke nuisance, engineers insisted on what was considered the main essential, and which is the reverse of the present practice, namely, that boilers should be *large enough;* and that waste, injury, and the smoke nuisance, were the necessary results of making *small boilers do the work of larger ones.*

Pressed by the value of space in marine vessels, engineers have, however, no alternative. In the arrangement of the vessels sufficient space is not allowed; all considerations are made to yield to large holds, or large passenger accommodation, while the boiler, the very source of its power, is shorn of its necessary proportions. Into the short space of ten feet three inches, the marine boiler we have just been considering (of above 300 horse power) had literally to be stowed, and not one inch to spare. To this shortness, therefore, in the boiler, is attributable the violation of all the laws of nature in working out the processes of combustion, circulation, and evaporation. Engineers are required to construct small boilers to do the work of large engines, the evil of which has been so well illustrated by Mr. Fairbairn in his late publication. Under these imperative instructions, they inconsiderately turned to the plan of the locomotive. The owners of steam vessels will in time find out their error. It is, however, unreasonable that limits should first be imposed on the engineer which are incompatible with efficiency and economy, and that he should then be condemned for not providing the due quantity of steam, and the required amount of pressure; for causing too heavy a consumption of coal; the frequency of injury to the furnace-plates; the waste of fire-bars; the great nuisance of smoke; and the rapid deterioration of the boilers themselves.

The consideration of these results lead to the conclusion, 1st.

That the system of numerous small tubes is radically erroneous, both with reference to the carrying and transmitting the heated products *within* them, and to the currents of steam and water *outside* them. 2ndly. That the placing the mass of tubes *above* the furnaces and flues, renders the application of the tubular system doubly vicious, by its interference with the functions of the steam and water; thus directly intercepting and obstructing their rising and descending currents. 3rdly. That the short boiler, with its short run system, is directly opposed to the operations of nature, as regards the mixture, heating and combustion of the gaseous portion of the fuel, with the very large quantity of atmospheric air which is absolutely required.

On the peculiarities of the tubular system, Mr. Craddock, having been more comprehensive than other writers, merits attention here, and the more so, as he observes, "I have been thus particular *in enumerating all the objections* that I have been enabled to collect, as being brought against tubular boilers." These objections are thus stated: —

1st. Liability to priming or steam passing off to the engine mixed with water.

2nd. Irregularity in the pressure of the steam from the small quantity of water such boilers generally contain.

3rd. Liability of the tubes to become furred up by deposit.

4th. Greater complexity.

5th. Greater original cost.

6th. Greater liability to derangement.

Now these objections are chiefly of a mechanical nature, while those which are overlooked, have reference to other and more important influences on combustion and its processes.

To Mr. Craddock's enumeration of objections may then be added the following, viz.: — 1st. Forcing the products of combustion (carbonic acid, nitrogen, and steam,) into the narrow orifices of the tubes, and thus producing the most unnatural and injurious mixtures with the flame, from which, in the order of nature, they had just separated themselves.

2nd. Dividing the flame into numerous small portions, thus lowering and attenuating its temperature before the process of combustion could have been completed.

3rd. Shortening the flame and diminishing its radiating power, by the conversion of the carbon of the flame into the form of soot.

4th. Practically reducing the available surface, by confining it to that portion of the tubes through which the products of combustion pass.

5th. Impeding the ascent of *the steam*, not only from the surface of the tubes, but from that of the flues and furnaces directly under them.

6th. Obstructing the circulation of *the water*, both in its upward and downward currents, by the narrow and intricate courses round the tubes.

7th. Shortening the run, or distance along which the heated products have to pass from the furnace to the up-take, where they become useless or dangerous.

8th. Increasing the already *too-rapid current* of those products, such current being always the more rapid as the area of the tubes is contracted.

9th. Diminishing the *available time* which the processes of combustion, and the transmission of heat naturally and absolutely require.

10th. Practically confining the generation of the steam to the furnaces and the plate-surface in connection with them.

The omission of these serious objections are the more remarkable, as Mr. Craddock has, himself, justly observed, that "*Time being one of the elements of first importance* in bringing about an uniformity of temperature in adjacent bodies, it follows, that the *greater the time* the hot matter (the products) is in contact with the surface of the boiler, the nearer will it approach the temperature of the water within; or, in other words, the *less heat will pass away unabsorbed* by the water." Now the direct effect of the tubular system is to shorten the time, and increase the rapidity of the current; thus creating the very evils he deprecates, by causing a greater portion of the heat to pass away unabsorbed.

Mr. Craddock further observes, and in the words of the first part of this treatise: "The most obvious way to produce perfect combustion, or to prevent smoke, is to supply the air that is required to produce the combustion of the carbon, or glowing coke remaining after the gases are dissipated at the bottom of the grate; whilst the *air required for the combustion of the carburetted coal-gas, should be supplied in such a manner as to come into due admixture with it, before it is cooled down below the temperature of ignition.*"*

Here is a true summary of what is required, as to air and temperature; yet the direct effect of the tubes, with their small orifices, is to cool down the gas below that temperature. Again he adds, "But the mere supplying the air in sufficient quantity at the proper place, and even with a sufficiently elevated temperature, is not the only condition requisite, *as the atoms of oxygen must be brought into close proximity with those of the gas to be ignited.*"

The conditions of perfect combustion are here clearly pointed out; yet so far from the tubular system which he advocates being in accordance with these conditions, it is in direct opposition in all that regards quantity of air, time, place, and temperature.

On the same point he observes, "Bringing such a vast quantity of the two gases (carburetted hydrogen and atmospheric air) into such close proximity, in the *short time* the gases are passing through the furnaces, and before they are too much lowered in temperature to be inflamed, is a matter of some difficulty, though of great importance to the prevention of smoke, and the greatest production of heat."

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* Mr. Craddock observes, "Here I am bound to say, that Mr. Williams's plan meets the conditions which chemistry requires for perfect combustion, better than any other with which I am acquainted. Mr. Williams proceeds upon the principle of mixing the gas in the furnace with numerous small jets of air. These innumerable small jets, by reason of their more readily and completely mixing with the atoms of the combining gases, must be admitted to be well calculated to produce that intimate mingling which chemistry shews to be *absolutely necessary.*"

It appears strange, that notwithstanding this enumeration of the bad effects arising from "*the short time*" the heated products are passing, he should have omitted the worst feature of the tubular system, namely, its so *shortening the time and distance* as to render the required "close proximity" a physical impossibility.

CHAPTER XV.

ON THE USE OF HEATED AIR AND ITS SUPPOSED VALUE IN THE FURNACES OF BOILERS.

SINCE the appearance of the first part of this treatise, shewing the necessity for admitting air to the gases generated in the furnace, apart from that admitted by the ash-pit, numerous patents have been taken out for effecting that purpose.

With the view of obtaining credit for originality, none have attracted more attention than those which assumed that the air introduced was to be *heated*, and that it would thereby become more effective. These plans, however, do not merit notice, either on the ground of theory or practice. It is right, nevertheless, that the public be put on their guard against being misled by the many plausible theories connected with this *hot air* system.

Among the devices by which the public have been led astray, may be mentioned, the use of hollow bars, supplemental flues, calorific plates, self-acting valves, double grates, heated tubes, and such like contrivances,—some of which have already been noticed, — overlooking the fact, that the whole question, as regards furnaces, and the best use of fuel, depends on the bringing the solid and gaseous constituents of the coal and the atmospheric air together, in the proper way.

When these so called inventions came to be examined, it was found that they were incapable of imparting any sensible degree of heat to the great volume of air required. That they were, in fact, but so many proofs of the ingenuity of their respective advocates, and of the ease with which the public may be imposed on; and that the announcement of a scheme for consuming, or of preventing smoke, by the use of hot-air was a mere professional and *ad captandum averment*, based on no principle, justified by no proofs, and supported by no chemical or practical authority.

The idea that there was some undefined value in the use of hot-air, originated in the hot-blast system in the manufacture of iron. The principle or process by which iron may be melted has, however, so little relation to that by which the combustion of the coal gas in furnaces is effected, that no analogy whatever exists between them.

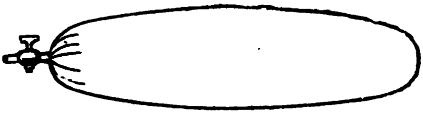
To shew in a still stronger point of view the deception practised, either on themselves or on others, it may be observed that it is not to the *coke* or incandescent part of the fuel on the bars that these patentees would apply the hot air, (as is done in the iron furnaces,) but to *the gases* in the furnace chamber, where the great disproportion between the relative bulk of the air required, and the gas, is already so obstructive of rapid union and combustion, and one of the great difficulties to be encountered.

With reference to the use of hot-air in boiler furnaces, no inquiry appears to have been made, either as to the temperature to which its advocates would raise it; or even whether, by any of their plans, it would be heated at all. Still there was something so plausible in the enunciation of a plan "for consuming smoke by means of hot air," that it was listened to by many who had no means of investigating its supposed merits, or detecting its fallacy.

The first question for inquiry here is, what would be the effect of heating the air before it would be introduced into the furnace? *Chemically*, no change whatever is effected. *Mechanically*, however, an important change takes place, namely, that its already unwieldy volume is still further increased. Thus, if a cubic foot of air be heated one additional degree, its bulk will be increased $\frac{1}{480}$ part; consequently, if heated by an addition of 480 degrees, its bulk will be doubled.

Let us then see if any effect be produced on its *constituents* by this enlargement of its volume. Let Fig. 123 represent a body of air at the temperature of 32°, and weighing 36 grains, viz., 28 grains of nitrogen, and 8 grains of oxygen; these being the proportions as they exist in the atmosphere.

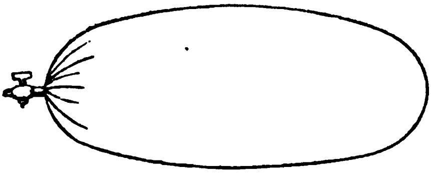
Fig. 123.



Air at 32° = 36 grains = 28 nitrogen, 8 oxygen.

Again, let Fig. 124 represent *the same weight of air,* heated to the temperature of 32 + 480 = 512°; its bulk being then doubled. Nevertheless, there are still but the same relative weights, viz., 28 grains of nitrogen and 8 grains of oxygen, ***and no more.***

Fig. 124.



Air at 32° = 36 grains = 28 nitrogen, 8 oxygen.

Now, as the efficiency of the air in producing combustion and generating heat is not in the proportion of the *bulk,* but of *the weight of oxygen* it contains, nothing has been gained by such increased temperature; while this great practical disadvantage has been incurred — that *double the volume* of air must be introduced into the furnace; and, of course, double the draught must be obtained before the same quantity of gas can be consumed.

The practical inconvenience of enlarging the volume of the air by heating it is easily illustrated; for if the oxygen of 300,000 cubic feet of air, at atmospheric temperature, be required for combustion of one ton of coal, it would require that of 600,000 cubic feet if raised to 512 degrees—a volume which no *natural draught* would be equal to.

Sir H. Davy says,—"By *heating strongly gases* that burn with difficulty, the continued inflammation becomes easy." Thus, as they are more easily inflamed when hot than cold, we have this testimony in favour of heating *the gas* rather than *the air*. With reference to heating the air, and thus expanding it, Sir H. Davy does not appear to have attempted it; but he has done what was more to the point—he tried the effect of *condensing* it. Professor Brande says,—"Sir H. Davy found considerable difficulty in making the experiments with precision; but he ascertained that both the light and heat of the flames of sulphur and hydrogen were *increased in air condensed four times*." This is decisive against *heating the air*, and in favour rather of *condensing* it.*

If, as already shewn, by heating the air we necessarily enlarge its bulk, and reduce the weight of oxygen in each cubic foot, we as necessarily diminish its efficacy in the furnace. Under such circumstances, the only alternative would be the increasing the draught, to compensate by increased quantity for diminished weight. Were it possible to heat the air without causing any enlargement of its bulk, we should then be in a position to decide on the relative merits of air at any given temperature. As, however, that is impossible, it is indisputable that we gain nothing by heating the air, more especially when we do so by the suicidal means of taking heat from the very furnace in which it was to be used, while we should seriously embarrass ourselves by having to increase the draught, and which could only be done by some mechanical blowing apparatus.

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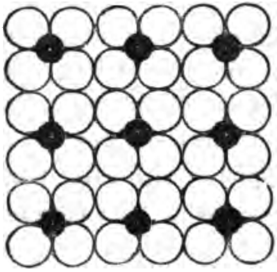
* Mr. David Mushet, in a letter on the hot air fallacy, well describes people flying to produce "a great revolution in steam engine furnaces, by applying hot air to the mere combustion of coal;" and settles the question at once when he says, "The value of *dense air* in promoting combustion is so undeniably established, that we should do better to attempt to *solidify it*, in contact with combustible matter, rather than to *volatilize it*."

Again, see the physical difficulty which heating the air would create in the preliminary operation of mixing: the atoms of gas being thrown at a greater distance from each other, by the enlargement of the bulk of the *intervening air*, as shewn in the annexed figures.

Fig. 125.



The large circles represent atoms of air, and the small black circles those of the gas; each of the latter being in contact with four of the former, equal to ten times its volume.

Fig. 126.

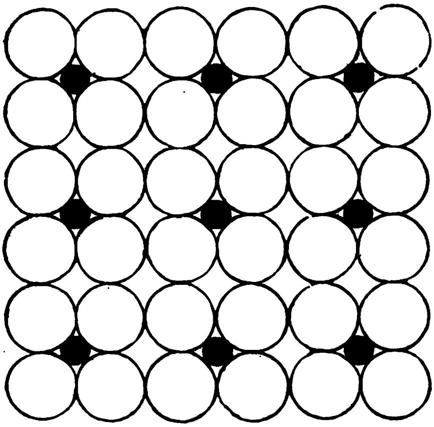


Fig. 126 represents the same *weight* of gas and air; the only difference being, that the air is shewn with its enlarged volume consequent on its increased temperature.

Here is truly represented what would occur by heating the air, the atoms of gas being thrown so much further apart, and consequently producing a corresponding difficulty in effecting that atomic mixture which is the main requisite of combustion. Thus, in whatever point of view the subject is considered, it is manifest no chemical or practical good can be effected by heating the air.

The use of hot air having engaged the attention of Mr. Prideaux, in connection with some departments of the manufacture of iron, he endeavoured to reduce his theory to practice; but candidly admits that "*his anticipations were not realized.*"

His observations, however, as given in his treatise already referred to, are so conclusive against the use of hot air, and so confirmatory of what is said above, that it can only be a matter of surprise he should have lent himself to the hot air fallacy.

He correctly observes,—"There is, no doubt, more heat contained in the products of combustion from a given weight of coal and air heated before ignition, to 720°, than would be contained in the products of the same quantities *by weight* of gases ignited at the temperature of 60°. When we take given *measures*, however, instead of given *weights, the case is reversed.*"

This is the whole case of the furnace: it is not the *measure* of the air introduced, but the *weight* of oxygen in each cubic foot that will influence the amount of heat generated. His reasoning throughout is "in explanation of the effect of hot air in *diminishing* the heat of the working chamber of reverberatory furnaces," and he might add, *à fortiori* in the furnaces of boilers, where no aid could be had from mechanical draught or pressure, to counteract the effect of that increased volume which heating the air would produce.

Again, he observes, "Whenever I took any steps to effect this object in the puddling furnace, I encountered the fact, that precisely as my arrangements for *heating the air* became more perfect, did I destroy the draught through the fuel, deaden the fire, and lessen the yield of iron. This unexpected result I attributed to the rarifaction of the air in the ash-pit. When the atmosphere is 60°, air is *double in volume* at 568°. When thus rarified *a much smaller quantity will pass in a given time, under the ordinary pressure of the atmosphere,* than would pass were the air at 60°, and, consequently, of double the density. The result is, a greatly diminished draught, and less intense combustion; and it is to *not having rightly appreciated these conditions that the numerous failures which have been incurred in attempting to apply heated air to furnaces, must, in part, be attributed.*"

Reasoning cannot be more correct, and at the same time more conclusive, against the error of attempting to increase the efficacy of the air, in the combustion of coal gas, by heating it.

CHAPTER XVI.

ON THE INFLUENCE OF THE WATER GENERATED IN FURNACES FROM THE COMBUSTION OF THE HYDROGEN OF THE GAS.

ALREADY many proofs have been given of the injurious results of the tubular system, where gas and flame have to be dealt with. There is one other circumstance still to be mentioned, and which demands particular attention, namely,—the generation of a large quantity of *water* in furnaces in which coal gas is produced and consumed, and which, being in the form of steam, becomes the largest product of that combustion.

In the ordinary use of coal gas, the presence of this water of combustion attracts no attention,—generated as it is in small quantities from the flame of each separate burner. From the enormous quantity of gas, however, which is hourly generated and consumed in large furnaces, the great quantity of water formed will be found accompanied with evils of a serious magnitude, unless due provision be made for its disposition. It seems strange that the numerous writers on the construction of boilers, and the combustion carried on in their furnaces and flues, should have omitted all reference to this great quantity of water, and the important difference in the mode in which it is disposed of, in flue and tubular boilers.*

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* It appears, by a paper read at the Institution of Civil Engineers, June 13, 1843, that in consequence of the serious injury sustained by the books in the Library of the Athenæum, London, the attention of Mr. Professor Faraday, as well as of other scientific members, was drawn to the subject of ventilating the lamp burners. The result was the adoption of a system, by which the

The fact of this great quantity of water being produced admits of no doubt. Bituminous coal, we have seen, contains from 5 to 6 per cent. of hydrogen, and as each pound of hydrogen, in combustion, combines with eight pounds of atmospheric oxygen, the product is 9 lbs. of water. Each hundred weight of coal then, containing on an average 5½ lbs. of hydrogen, the product will be nearly 50 lbs. of water. Thus the gas from each ton weight of coal will produce about half a ton weight of water, *in the form of steam.*

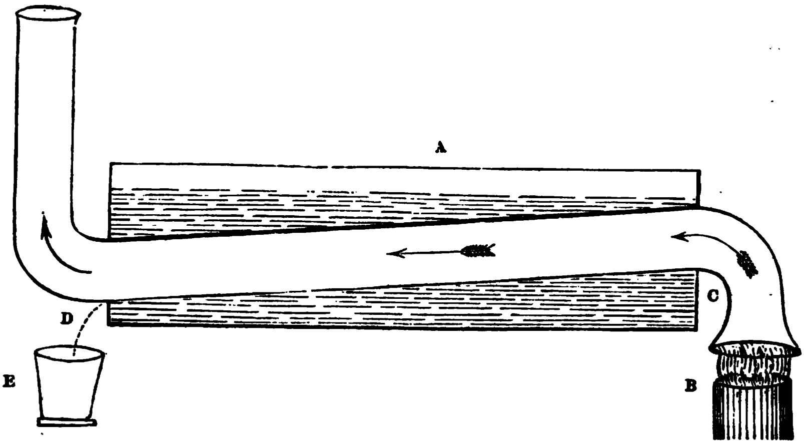
When the coal gas is generated in the furnace, the first operation towards its combustion is the union of its hydrogen with the oxygen from the air, forming water. This chemical union, as already shewn, produces that intense heat which raises the other constituent—the carbon, to the temperature of incandescence in the form of bright visible flame. It is this heat which, on being applied to some solid body, as charcoal, or lime, produces the extraordinary luminosity exhibited in the oxy-hydrogen microscope.

The water thus formed, flies off in invisible radii, from the surface of the flame, and with the explosive force due to its high temperature. The presence of this water may be made visible by approaching any cold polished metallic body (as the blade of a table knife), near to, but not touching, the flame of a candle. The previously invisible radii of steam will then be seen condensed, like moisture, on the polished surface.

This may be exhibited on a larger scale by holding a new tin kettle of cold water, with a bright bottom surface, one or two inches above the glass chimney of an Argand gas burner. The water of combustion will soon appear condensed on the bottom, in presence of, and as it were in defiance of, the great heat to which it is exposed. This will continue until the water in the vessel reaches a temperature of 80°.

water, and other products of the combustion of the gas, are effectually carried away. The plan consists of placing a second glass cylinder, larger and taller than the ordinary one, over it. This outer glass is closed at the top, and the products, passing downwards between the two glasses, are carried away by a metal tube to the chimney stack.

Fig. 127.



By the apparatus shewn in the annexed Figure 127, this water may not only be condensed, but collected. It consists of a tin vessel, A, about four feet long, filled with cold water:—the flame of a large gas burner B, and the heated products passing through the flue C, slightly inclined from C to D, to favour the escape of the condensed water of combustion.

The flame and other products of the gas being directed through the flue, the steam will be condensed within it, and the water will continue dropping from the lower end into the vessel E, as long as the flue remains sufficiently cold:—the other products passing off by the funnel, and at a very low temperature.

This process may be continued for any length of time by having some ice in the water to keep the temperature of the flue sufficiently low to promote immediate condensation of the steam. Here the *flame* appears literally converted into *water*, these being the only two of its products that are visible.

It is now to be considered, how is this great volume of steam to be disposed of.

In boilers on the *flue* system where there is sufficient room, this steam produces no injurious effect, by reason of its having space to *separate itself* from the flame, as rapidly as it is generated.

In the tubular system, however, the injurious influence of this mass of steam is serious and palpable. Instead of passing away in a flue, with a sectional area of 8 or 10 square feet, it is forced by the draught into the hundreds of small metallic tubes of but 2 or 3 inches area, and thus brought into immediate and even atomic contact with the flame *from which it had just been separated*,—both struggling to enter their narrow orifices at the same moment. The immediate and inevitable result of this compulsory mixture is, the cooling the atoms of the carbon, which gave luminosity to the flame, and its consequent extinguishment, precisely as the steam formed by the combustion in Phillips' fire annihilator acts on flame, when brought into contact with it. By the tubular system, the great body of steam being thus mechanically compressed into the closest possible contact with the flame on entering the mouths of the tubes, is compelled to act the part of the annihilator.

It is this artificial mixture of the dry carbon with the steam that forms the sooty incrustation in the interior of the tubes, flues, and chimney. Were it not for the presence of this steam, the dry pulverulent carbon, such as we see collected on the wick of a tallow candle (where the new-formed water has no access to it) would, from its levity and dryness, pass off rapidly by the chimney: forced, however, into contact with the steam, a black, pasty, non-conducting mass is formed, adhering to whatever it touches, and soon, from the heat, becoming hard and solid.

It need scarcely be observed, that nothing of this kind occurs in the tubes of the locomotive; no hydrogenous gas being generated—no steam of combustion formed, and, consequently, no carbon or soot deposited.

The provision which nature has made for the immediate separation of the water from the heated flame may be noticed in what takes place in the flame of a candle. When left to themselves, the several products of the combustion of the gas, rapidly and effectually separate, so as not to interfere with each other, or reduce the high temperature on which perfect combustion and luminosity depend.

In the flame of a candle, the undecomposed and unconsumed gas appears surrounding the wick, and in the centre of the brilliant incandescent carbon. Outside this white exterior, and forming a semi-transparent film of $\frac{1}{10}$ of an inch in diameter, may be observed the vertical stream of carbonic acid gas, the product of *the carbon;* while that of the other constituent, *the hydrogen,* were it visible, would be seen flying off in radii, until absorbed into the surrounding atmosphere.

Fig. 128.

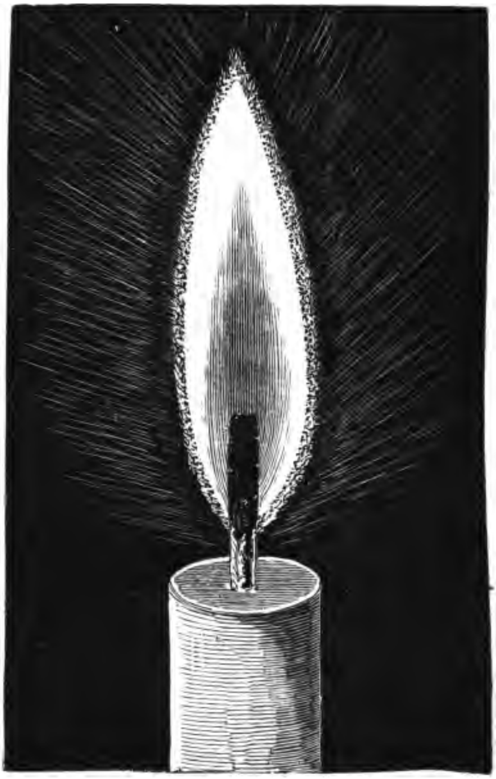
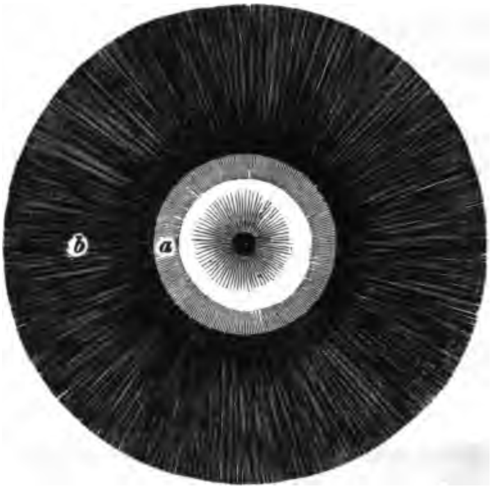


Fig. 129.



The annexed Fig. 128 will represent a vertical, and Fig. 129 a cross section of the flame: *a* representing the carbonic acid, and *b* the radiating steam. Instead of imitating this process of nature, in keeping asunder those several products (carbonic acid, nitrogen, and steam,) which would neutralize each other, we force them into the most unnatural mixture and union, regardless of their chemical action when brought into contact. We here see how absolutely necessary it is that in every stage and process of combustion we keep in view those truths of nature which chemistry has so clearly indicated.

CHAPTER XVII.

ON INCREASING THE HEAT-TRANSMITTING POWER OF THE INTERIOR PLATE SURFACE OF BOILERS.

THIS branch of the subject has hitherto been entirely overlooked. Inquiry has shewn that the mere providing a large internal surface will not suffice for taking up the heat generated in large furnaces; and that, to turn to account any portion of that which, under the best arrangement, is now absolutely lost, we must look to other means than the tubular system.

The question for consideration is, whether an iron plate cannot be made to transmit more heat to the water than is due to its mere superficial area. From what has been shewn of the slow rate at which the air enters the furnace, when *mechanically divided into jets or films*, we are not to infer that the gaseous products, when raised to a high temperature *within the furnace*, would pass through the flues at the same slow rate. On the contrary, we find those products are hurried across the face of the plates at a considerably increased velocity. This it is which calls for increased means of transmission from the heat to the water, when larger engine powers are employed, and more fuel is consumed.

Under the most favorable circumstances of boilers, a larger portion of heat will be lost than would be required for merely producing the necessary draught. Experiments were, therefore, made with the view of counteracting this great waste of heat, and which established the fact, that it was possible, to a certain extent, to increase the quantity of heat transmitted by any given surface of plate. It is true a plate, 10 feet by 10, equal to 100 square feet, presents the same amount of surface area as one of 100 feet long by 1 foot wide. As a steam generator, however, the effect would be very different:—the *lineal run* or distance travelled over being as ten to one, and occupying *ten seconds* of time in the first, and but *one second* in the other.

When the gaseous products of combustion are carried through flues or tubes, this lineal current passes *at right angles to the line of transmission* of the heat through the plate. If, however, we heat one end of a rod of iron, a large conducting power is brought into action, the heat passing *longitudinally* along its fibres. Now this is the power that has been here rendered available.

Independently of the *conducting* power which a metallic pin or rod may have, it possesses then a *receiving* power, greater than is due to its mere diameter.

Suppose an iron or copper pin of half an inch diameter, inserted in a plate, and projecting into the flue *three inches beyond its surface, and across the current of the heated products.* In such case the portion of such plate occupied by it will be equal to a disc of but half an inch in diameter, while the pin itself will present a heat *receiving surface* of 4½ inches. By this means we obtain an effective heat *receiving* surface nine times greater than the area of the plate which the pin occupied. If, then, a series of these conductors be inserted in the flue and furnace plates, there will be an increased effect from the circumstance of the current of the heated products *being directed against them,* instead of *passing along the surface* of the plate.

The popular impression that the three-legged pot boiled sooner than the one without legs, though it passed as a fable, was, nevertheless, a true one,—the legs acting the part of heat conductors. This was tested by having a large pitch-pot constructed with twenty legs instead of three—the bottom being thus furnished with so many projecting conductors, each six inches long. The result was, that pitch or water was more rapidly boiled in this than in one of the ordinary kind. The principle of projecting heat conductors thus was shewn to be entitled to attention and practically available.

Fig. 130.

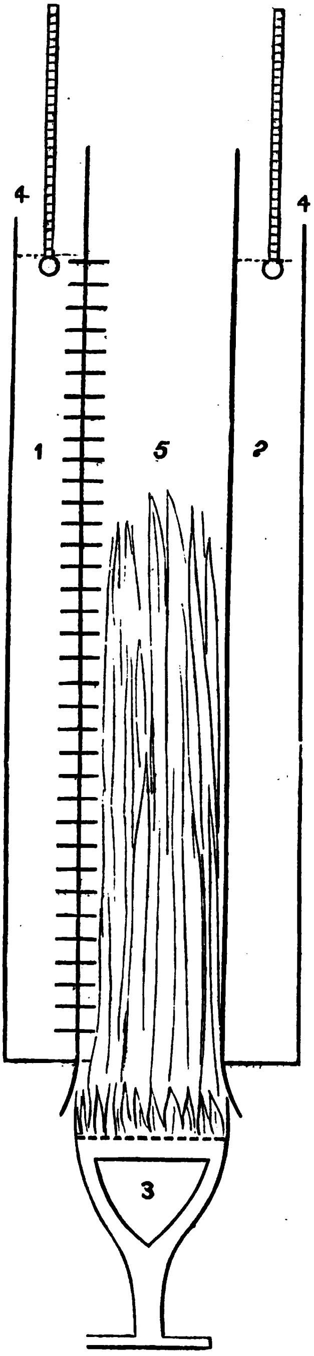
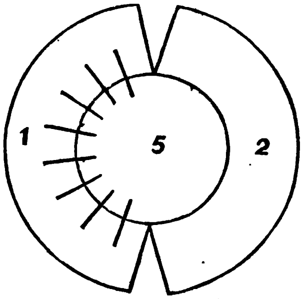


Fig. 131.



The following experiment is illustrative of the increased evaporative effect produced by the conductor pins. In Fig. 130, 1 and 2 are tin vessels containing the same quantity of cold water, 1 being furnished with the conductors made of ⅛ copper wire, and 2 left plain; a thermometer, 4, being suspended in each: 5 is a vertical flue, through which the products from the flame of a large gas-burner passed. Fig. 131 is a sectional view of the same. The temperature in both vessels was taken in two-minutes' time. The following are the progressive rates at which the water was raised to the boiling point.

Pan with Conductors.		*Pan without Conductors.*			
Initial Temperature,	61°	Initial Temperature,	61°	16 .	163°
After 2 minutes,	75°	After 2 minutes,	70°	18 .	171°
„ 4 „ .	95°	„ 4 „ .	82°	20 .	181°
„ 6 „ .	124°	„ 6 „ .	101°	22 .	188°
„ 8 „ .	151°	„ 8 „ .	118°	24 .	196°
„ 10 „ .	177°	„ 10 „ .	130°	26 .	203°
„ 12 „ .	201°	„ 12 „ .	146°	28 .	210°
„ 13 „ .	212°	„ 14 „ .	156°	29 .	212°

Thus it appears that the water in the pan with the heat conductors, was raised to the temperature of 212° in 13 minutes, while that in the plain pan required 29 minutes.

The following experiment shews still further the value of assisting the evaporative power by the aid of these conductors.

Three tin boilers, as in the annexed figures, were placed in connection with a large laboratory gas burner. In each was put 22 lbs. of water; 30 cubic feet of gas were consumed in each experiment, in two hours and forty minutes. The result was as follows:—

	lbs.	oz.	
No. 132, without conductors, evaporated	4	14	of water.
133, with conductors on one side only	7	14	„
134, with conductors projecting on both sides	8	5	„

Fig. 132.

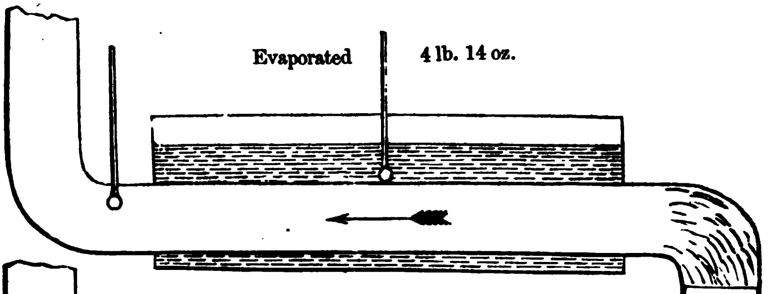


Fig. 133.

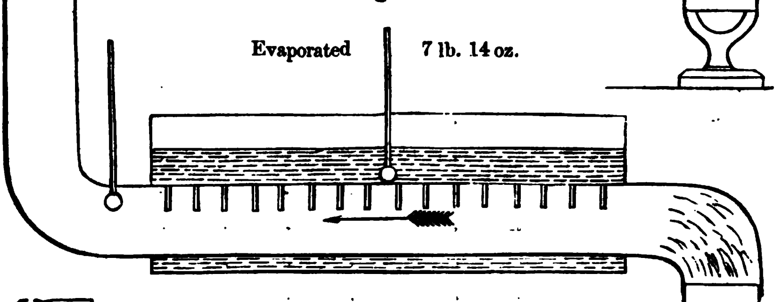
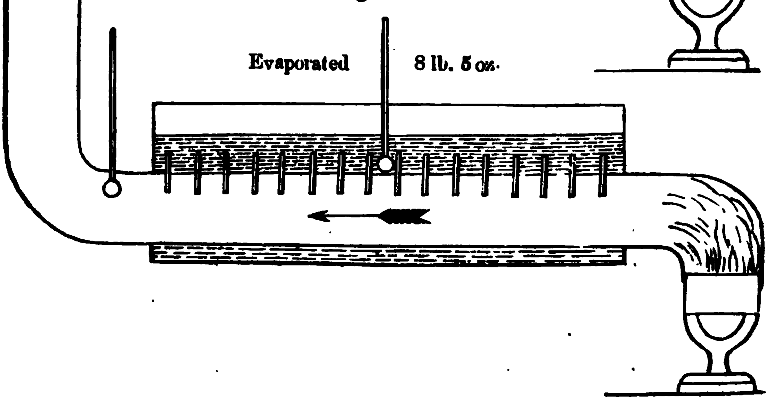


Fig. 134.



The quantity of gas consumed was the same in both cases, —the heat generated was the same,—the area of flue plate was the same,—the difference in effect was therefore alone produced by the greater quantity of *heat transmitted to the water, longitudinally, through the conductors.*

In this case, the heat conveyed to the water, and that escaping by the funnel, shewed that where the waste heat was greatest, the evaporative power was necessarily the least.

Fig. 132.

Pan without Conductors.

Gas consumed.	Heat of Water.	Heat escaping.
	58	62
5 feet	120	382
10	152	390
15	162	395
20	164	396
25	166	402
30	166	406
	988	2432

Evaporated 4 lbs. 14 ounces.

Fig. 133.

Pan with Conductors projecting on one side.

Gas consumed.	Heat of Water.	Heat escaping.
	58	62
5 feet	143	257
10	160	280
15	172	385
20	178	392
25	186	300
30	188	320
	1085	1996

Evaporated 7 lbs. 13 ounces.

Fig. 134.

Pan with Conductors projecting on both sides.

Gas consumed.	Heat of Water.	Heat escaping.
	58	62
5 feet	152	248
10	174	273
15	178	276
20	182	278
25	186	282
30	188	284
	1110	1703

Evaporated 8 lbs. 5 ounces.

The comparison of the three pans then stands thus:—

		Heat retained.	Heat lost.
1	Pans without conductors	988	2432
2	„ single conductor .	1085	1996
3	„ double conductor .	1110	1703*

Numerous instances might here be given of the successful application of these heat conductors both in land and marine boilers, in which several thousands of 3-inch pins have been inserted, and where they have been for years doing constant duty without a single failure or leakage.

It is here worthy of remark that M. Peclet, in his *Traité de la Chaleur*, has suggested a similar mode of increasing the transmitting power of a given area of a plate. He begins by distinguishing the three characteristics of a plate. First,—the reception of heat by one side. Second,—its emission from the other side. And Third, the power of conduction through the body or thickness of the plate. He then observes that a plate of metal has the power of transmitting far more heat than it is

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[*] These, and other experiments in illustration of the same results, were published in the Mechanics' Magazine, in 1842.

really and practically called on to transmit, on account of the current by which the heat is *hurried along the face of it.*

Among the modes of counteracting this rapid current, he observes:—" If the plates were *crossed by metallic bars, which should project to a certain extent into both fluids* (gaseous or liquid), one of which was to heat the other, the extent of surface contact being increased (by the bars), *the quantity of heat transmitted would be increased,* and the more so, as the stratum or film of the fluid in contact with the bars would be continually changing." He then supposes a case of hot air (as the products of combustion in a flue) passing through a tube surrounded by water, to which the heat was to be conveyed, and being *traversed by metallic bars projecting both inwards and outwards.* In such case the *interior* projections will become heated, and this heat, *passing along the bars, will be given out from their surfaces.* It will here be seen that this is identical with the illustrations here given.

M. Peclet observes, that this arrangement *has not hitherto been put in practice.* He was not aware, however, it may be assumed, that it had been previously, and many years, in practice both in land and marine boilers.

Conductor pins were applied to the boilers of a six-horse engine. The result was, that each inch deep of water which previously required 28 minutes to evaporate, was, by means of the conductors, done in 21 minutes.*

Encouraged by these results, conductor pins have been, during the last 12 years, introduced into many marine and land boilers with unquestionable success. After many years of observation as to their durability, the conclusion is, that a projection into the flues of 3 inches is the most advisable. If longer, they will burn away to about that length.

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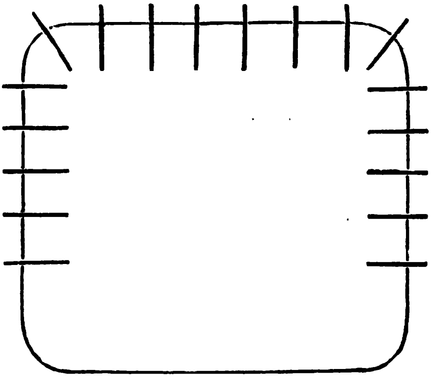
* Dr. Ure, impressed with the same view, made some experiments with corrugated plates. The effect, he observes, (see his Dictionary of Arts,) was remarkable: the water evaporated when the current of heated products passed across the corrugations, and, as it were, striking against them; being so much greater than when it ran in the same direction. On the same principle, the heat transmitted was increased when the current of the products was intercepted by the conductors.

Supposing the conductor to be made of half inch rods and inserted at intervals of 3 inches, the strength of the plate has been tested and found to be rather improved, the conductor pins apparently acting the part of floor bridging, and giving increased stiffness.

Supposing the area of the flue to be two feet square, then the introduction of the pin conductors may be as shewn in the annexed Fig. 135.*

Fig. 135.



As illustrative of the mode and extent to which the system has been practically applied, Fig. 136 and Fig. 137 represent a plan and section of the boilers of "*The Royal William.*" These boilers have been in constant use for the last 5 years, and with the most perfect success as regards economy of fuel,—freedom from the smoke nuisance,—evaporative power, and durability;—the number of conductor pins are 4359.

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* The principle of these conductor pins has been adopted in sugar boiler pans, and other descriptions of evaporative vessels; and would no doubt be applicable to the operations of brewing and distilling.

Fig. 136.

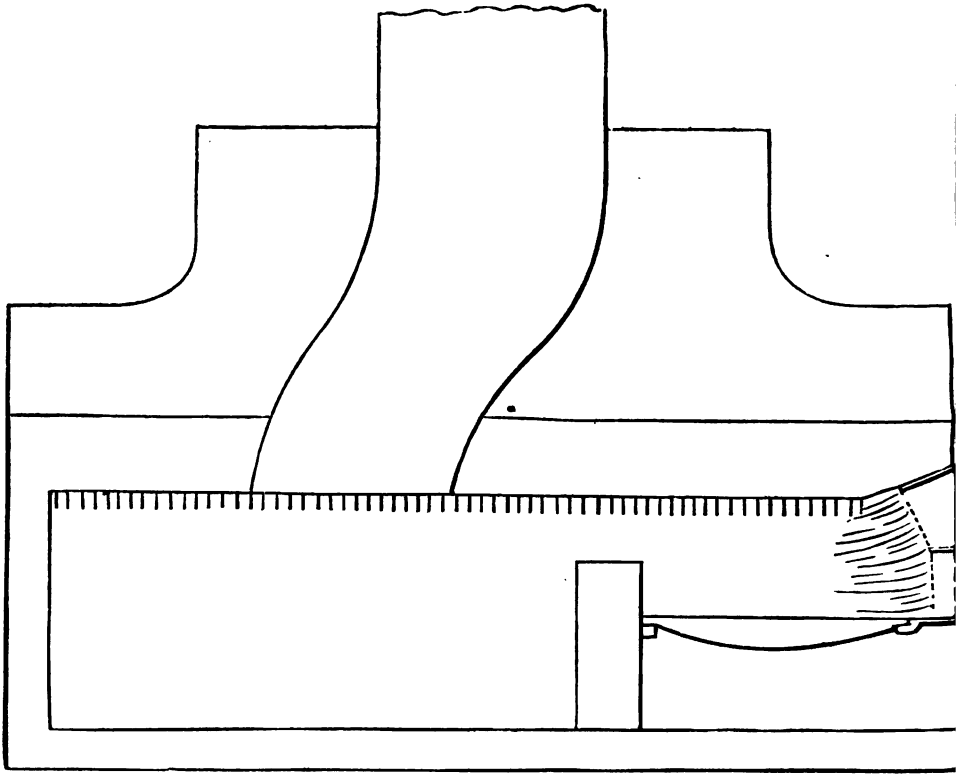
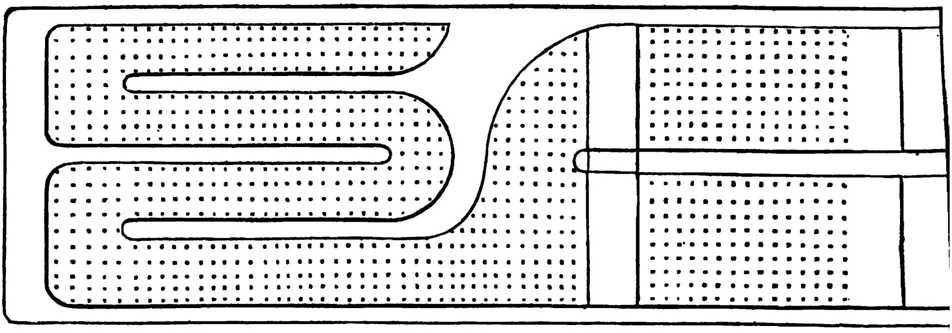


Fig. 137.



The plan of the boiler described as Lamb and Summers' patent, may here be given, inasmuch as one of its peculiarities is connected with the use of the heat conductors, and precisely corresponding with the description given by M. Peclet,—the flue being "*traversed by metallic bars*," and which here act the double purpose of *stays* (as in locomotive boilers) and *heat conductors*.

In the boilers of the Peninsular and Oriental Steam Company's Ship "*Pacha*," as in Figures 138 and 139, the stays which act the important part of double heat conductors are of ⅝th-inch iron; of these there are 1920, and as they act effectually on the water spaces on each side, do the duty of 3840 most effective heat conductors.

The Patentees state that the superiority of this plan over the common tubular "consists in the facility for cleaning; that is, for the removal of the scale or deposit which takes place so largely in the boilers of sea-going vessels. The vertical water spaces of these boilers afford an easy means of cleaning the sides of the flues, and so enable the water to come in contact with the iron flue. That in tubular boilers the horizontal position of the water spaces between the tubes renders it an impossibility to clean them; the consequence of which is, that a constant succession of deposit takes place. The flues of boilers which have been constantly at work since 1850 present no appearance of deterioration."

Fig. 138.

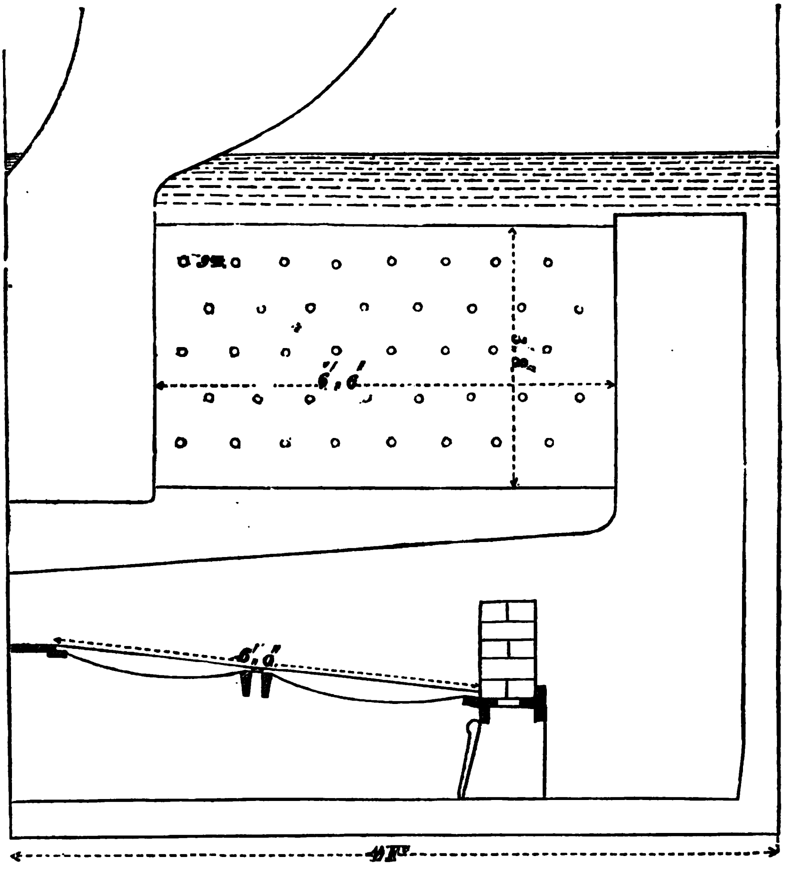
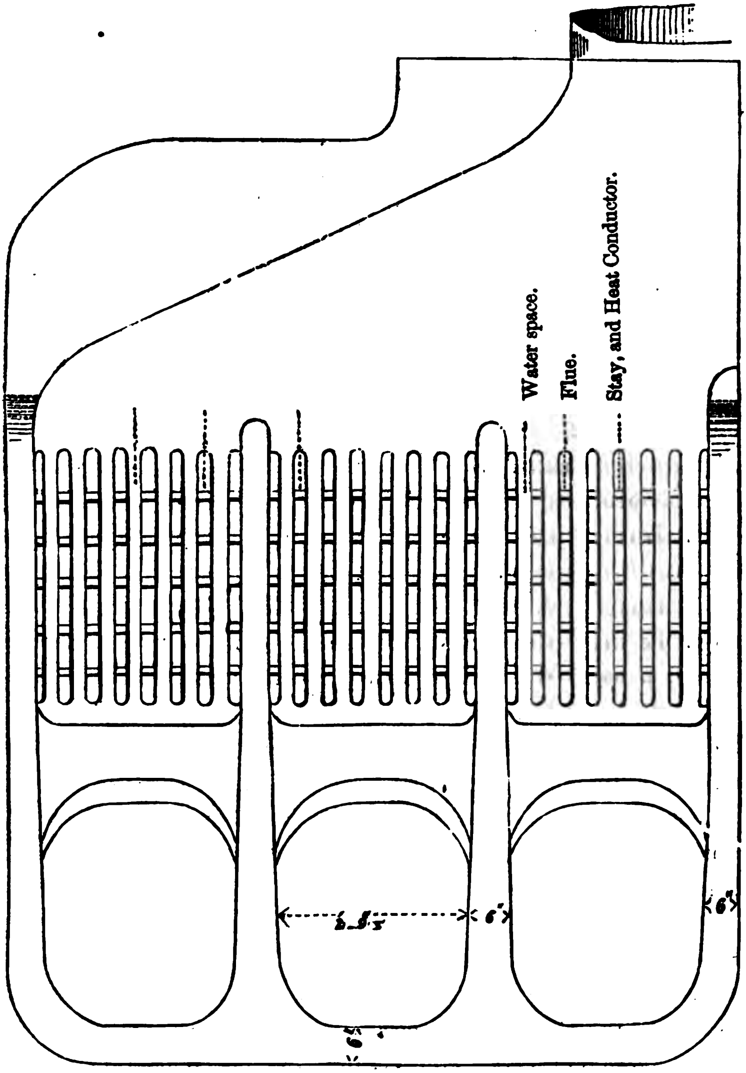


Fig. 139.



The principle is too self-evident to avoid adoption hereafter in all descriptions of vessels where heat has to be communicated, or abstracted.

CHAPTER XVIII.

ON THE GENERATION AND CHARACTERISTICS OF SMOKE.

So much has been said and credited on the subject of the *burning* and *combustion*, and even *consumption*, of smoke; and it has been so often asked, *What is smoke?* that the subject cannot here be dismissed without comment.

Dr. Lardner has observed, that on coal being thrown on a furnace, "*a smoke* will arise, which, passing into the flue over the burning coal, will be ignited." With equal correctness might he have said, that on coal being thrown into a heated retort, *a smoke* will arise, which, passing into tubes, is conveyed to our apartments, and there ignited, giving out both light and heat. When palpable errors in description are committed by scientific men, it can be no matter of surprise that an unobservant public should become familiarized with such absurdities as "smoke burning," and "smoke-consuming, furnaces."

Before the characteristics of combustible gases were known, it was natural that all coloured vapours, rising from heated bodies, should be called smoke. So soon, however, as the properties of the several gases were correctly ascertained, through the researches of Davy and Dalton, the misapplication of the term became unpardonable on the part of those who profess to be public instructors on the subject.

The gas from which smoke proceeds, in a furnace or retort, is carburetted hydrogen. The constituents of this gas have been already described; each atom consisting of two atoms of hydrogen and one of carbon. This latter we are warranted in assuming to be a solid, contained, and concealed from view, by, or within the gaseous volume of the hydrogen, since carbon has never yet been produced in the form of a gas, nor hydrogen in that of a solid. It is only when their *chemical union*, in the form of the coal gas, is broken up, that the carbon becomes visible and tangible. Now this circumstance alone furnishes an unerring test of the difference between *gas* and *smoke;* a distinction which, we shall see, is capable of physical proof.

When we see a dark yellow vapour rising from heated coal, as at the mouth of a retort, or from a furnace, or domestic fire, after fresh coal has been thrown on, this colour is not occasioned by the presence of *carbon*, but is caused by the sulphur, tar, or earthy impurities which might happen to be in the coal. All these are subsequently separated from the carburetted hydrogen in the purifying process—the gas remaining transparent—so minute are the several atoms of the carbon, and so diffused are they when in connection with the hydrogen. That the *solid carbon is there*, notwithstanding this transparency, is proved by its subsequent liberation; as when a polished body is thrust into the flame of a candle or gas jet, and brought out with a deposit of the carbon on it. Carbon, in fact, when in chemical union with gaseous matter, is always invisible and intangible. The following experiment will sufficiently illustrate these facts, exhibiting both the *gas* and the *smoke* in their separate states of existence, and with their separate characteristics.

Fig. 140.

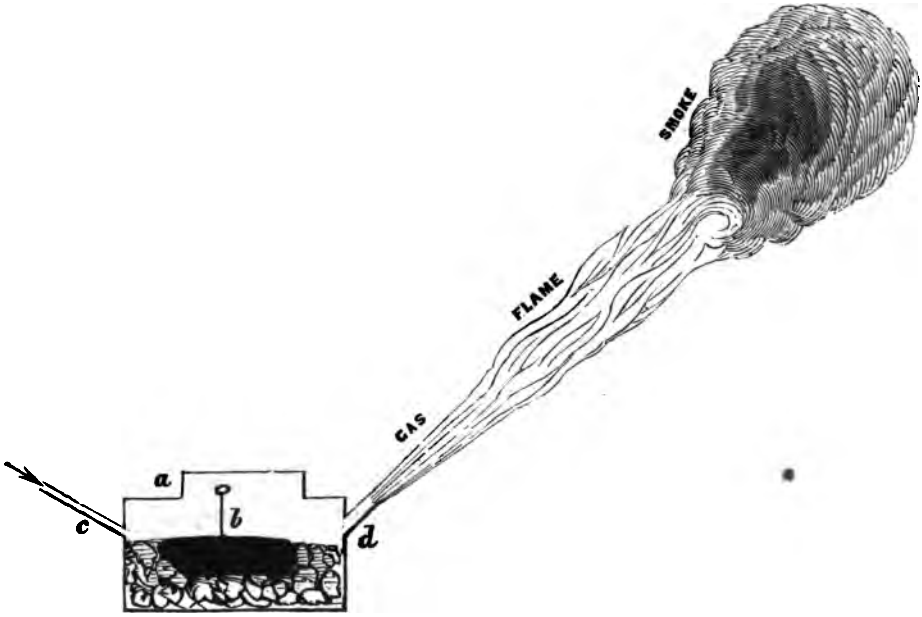


Fig. 140 represents a tin vessel *a*, capable of holding a quart measure; in it was placed some small coal, resin, and tar, to produce a quick and large development of gas. The lid being removed, an iron, *b*, made red hot, was introduced, and the vessel again close covered. A small tube is then inserted at *c*, to be blown into, as into a blow-pipe, to expel the gas in a stream.

By blowing through this tube, a copious volume of the gas will issue from the nozzle *d*. That the carbon in this gas is inaccessible, is proved by presenting a sheet of paper to the stream, and, although it may be slightly stained, if there be much tar present, no carbon, however, will be deposited.

On this stream of gas (many inches long,) being lighted, a lurid flame will be produced, but which, becoming cooled down before it can be sufficiently mixed with the air, produces a large volume of true smoke. Here, then, is exhibited *the gas*, *the flame*, and *the smoke*, at the same moment, and in succession, just as they are produced in the furnace,—the gas being converted into flame, and the flame into smoke.

Now let us examine the characteristics of each. The carbon in the gas, as already mentioned, is inaccessible, being concealed by or within the atoms of hydrogen respectively, and cannot be separated, or deposited on the paper. On being lighted, the hydrogen combines with the oxygen of the air forming steam, which flies off, as already described. The result is, the *liberation of the atoms of carbon*, either to be converted into carbonic acid, (if the heat can be continued,) or deposited in the form of the fine lamp-black powder, as we see it collected on the wick of the tallow candle. This may be tested by presenting the white paper to it, when a large quantity of this black carbon will be deposited on it. We here see the double error of mistaking *smoke* for *gas*, and then assuming that the former can be burned.

It may be well here to notice an error with which we are generally impressed, namely, that the cloudy volume of smoke, as we see it issuing from a chimney, and filling a large space in the atmosphere, is formed of carbonaceous matter.

With equal propriety might we say, if we put a few drops of ink into a glass of clear water, and thus give it a blackened colour, that the whole would become a mass of ink. This black cloud is merely the great mass of *steam*, or watery vapour, formed in the furnace, as already described, but *coloured by the carbon;* and when we consider, that no less than half a ton weight of water *(in the expanded form of steam)* is produced from every ton weight of bituminous coal consumed, we can easily account for the enormous volume and mass of this *blackened vapour* called smoke, as it appears to our vision, and the palpable error of supposing that this cloud of incombustible matter was capable of being consumed, or converted to the purposes of heat.

Were it not for this mass of steam the carbon would soon fall, as a cloud of black dust; but, being intimately and atomically mixed with the large volume of steam from the furnace, it is carried along by the atmosphere, only differing in colour, like the cloud of steam we see issuing from the chimney of a locomotive when in action.

With the view of bringing the subject to the test of high chemical experience and authority, I submitted to Professor Brande the following extracts from a printed paper, being the substance of one of my communications to a public auditory in Manchester, and here give his reply.

To W. T. BRANDE, Esq., *London*.

"Liverpool, Nov. 25, 1841.

"My dear Sir,—With this you will receive a copy of a printed paper on the 'Generation of Smoke,' written by me for the purpose of explaining the grounds on which I object, chemically, to the use of the term, 'the burning or combustion of smoke,' as applied by patentees to their respective plans of furnaces. This paper was intended not only as a justification of myself, as regards the chemistry of combustion, and the objects and effects of my own furnace, but as a reply to the 'smoke-burning' views of others, to which I am necessarily opposed.

"Wishing to have your views, professionally, on the chemical part of the subject, as stated by me in this paper, I have to request your opinion on the same.

"I am, very truly yours,

"C. W. WILLIAMS."

"ON THE COMBUSTION OF COAL AND THE PREVENTION OF SMOKE.

A consideration of the nature of the products into which the combustible constituents of coal are converted in passing through the furnace and flues of a boiler, will enable us to correct many of the practical errors of the day, and ascertain the amount of useful effect produced, and waste incurred. These products are:

1st. Steam—highly rarified, invisible, and incombustible.

2nd. Carbonic acid—invisible and incombustible.

3rd. Carbonic oxide—invisible, but combustible.

4th. Smoke—visible, partly combustible, and partly incombustible.

Of these, the two first are the products of perfect combustion, the latter two of imperfect combustion.

The first—steam—is formed from that portion of the hydrogen (one of the constituents of coal gas,) which has combined chemically with its equivalent of oxygen from the air—in the proportion of one volume of hydrogen to half a volume of oxygen; or, in weight, as 1 is to 8.

The second—carbonic acid—is formed from that portion of the constituent, carbon, which has chemically combined with its equivalent of oxygen, in the proportion of 16 of oxygen to 6 of carbon, in weight; or, in bulk, of one volume of the latter to two of the former.

The third—carbonic oxide—is formed from that portion of the carbonic acid which, being first formed in the furnace, takes up an additional portion of carbon in its passage through the ignited fuel on the bars, and is then converted from the *acid* into the *oxide* of carbon; thus changing its nature from an incombustible to a combustible. This additional weight of carbon so taken up, being exactly equal to the carbon forming the carbonic acid, necessarily requires for its combustion the same quantity of oxygen as went to the formation of the acid.

The fourth—smoke—is formed from such portions of the hydrogen and carbon of the coal gas as have not been supplied or combined with oxygen, and, consequently, have not been converted either into steam or carbonic acid.

The hydrogen so passing away is transparent and invisible; not so, however, the carbon, which, on being so separated from the hydrogen, loses its gaseous character, and returns to its natural and elementary state of a black, pulverulent, and finely-divided body. As such, it becomes *visible*, and this it is which gives the dark colour to smoke.

Not sufficiently attending to these details, we are apt to give too much importance to the presence of the carbon, and have hence fallen into the error of estimating the loss sustained by the blackness of the colour which the smoke assumes, without taking any note of the *invisible* combustibles, hydrogen and carbonic oxide, which accompany it. The blackest smoke is, therefore, by no means a source of the greatest loss; indeed, it may be the reverse; the quantity of invisible combustible matter it contains being a more correct measure of the loss sustained than could be indicated by mere colour.

This will be still more consistent with truth, should any of the gas (carburetted hydrogen,) escape undecomposed or unconsumed, as too often is the case.

In the ordinary acceptation of the term "smoke," we understand *all* the products, combustible and incombustible, which pass off by the flue and chimney. When, however, we are considering the subject scientifically, and with a view to a practical remedy against the nuisance or waste it occasions, we must distinguish between the gas as it is generated, and that which is the result of its imperfect combustion. In fact, without precise terms and reasoning, we disqualify ourselves from obtaining correct views either of the evil or the remedy.

Now, let us look at this gas, which we are desirous of converting to the purposes of heat, under the several aspects in which it may be presented under the varying degrees of temperature, or supplies of air.

In the first instance, suppose the equivalent of air to be supplied in the proper manner to the gas, namely, by jets, for in this respect the operation is the same as if we were supplying gas to the air, as in the Argand gas-lamp. In such case, one half of the oxygen absorbed goes to form steam, by its union with the hydrogen; while the other half forms carbonic acid, by its union with the carbon. Both constituents being thus supplied with their equivalent volumes of the supporter, the process would here be complete—perfect combustion would ensue, and no smoke be formed; the quantity of air employed being *ten times the volume of the gas consumed.* (See Fig. 141.)

Again, suppose that but one half, or any other quantity, *less* than the saturating equivalent of air were supplied. In such case, the hydrogen, whose affinity for oxygen is so superior to that of carbon, would seize on the greater part of this limited supply; while the carbon, losing its connection with the hydrogen, and not being supplied with oxygen, would assume its original black, solid, pulverulent state, and become *true smoke.* The quantity of smoke then would be in proportion to the deficiency of air supplied.

But smoke may be caused by an *excess* as well as a *deficiency* in the supply of air. This will be understood when we consider that there are *two* conditions requisite to effect this chemical union with oxygen, namely, a certain degree of temperature in the gas, as well as a certain quantity of air; for, unless the due temperature be maintained, the combustible will not be in a state for chemical action.

Now, let us see how the condition, as to *temperature,* may be affected by the quantity of air being in *excess.* If the gas be injudiciously supplied with air, that is, by larger quantities or larger jets than their respective equivalent number of atoms can *immediately combine with,* as they come into contact, a *cooling effect* is necessarily produced instead of a *generation of heat.* The result of this would be, that, although the quantity of air might be correct, the second condition, the required temperature, would be sacrificed or impaired, the union with the oxygen of the air would not take place, and smoke would be formed.

Thus we perceive that the *mode* in which the air is introduced exercises an important influence on the amount of union and combustion effected, the quantity of heat developed, or of smoke produced; and, in examining the mode of administering the air, we shall discover the true cause of perfect or imperfect combustion, in the furnace, as we see in the lamp. This circumstance, then, as regards the manner in which air is introduced to the gas, (like the introduction of gas to the air,) demands especial notice, as the most important, although the most neglected, feature in the furnace, and in which practical engineers are least instructed by those who have undertaken the task of teaching them.

We see, then, how palpably erroneous is the idea, that smoke, once formed, can be consumed in the furnace in which it is generated, and how irreconcilable is such a result with the operations of nature. The formation of smoke, in fact, arises out of the failure of some of the processes *preparatory* to combustion, or the absence of some one of the conditions which are essential to that consummation from which light and heat are obtained. To expect, then, that smoke, which is the very result of a deficient supply of heat, or air, or both, can be consumed in the furnace in which such deficient supply has occurred, is a manifest absurdity, seeing that, if such heat and air had been supplied, this smoke would not have existed."

Opinion of W. T. Brande, Esq., *Professor of Chemistry at the Royal Institution, London, on the preceding Paper.*

Royal Mint, 29th Nov., 1841.

Dear Sir,—I quite agree with you as to the distinction which ought always to be made and observed between the "prevention of the formation of smoke," and the "combustion of smoke after it has been made;" and also, as to the necessity of accurately defining what is meant by the term "smoke."

I have carefully perused the printed extract of your lecture on these subjects, delivered at the Victoria Gallery, Manchester, and am ready to admit the general correctness of the chemical principles upon which your views are founded. The *colour* of the smoke is, as you properly observe, no criterion of the loss of combustible matter, or of the waste incurred by any particular form of combustion.

Carbonic oxide, carburetted hydrogen, and various hydro-carbons, in the form of *vapour*, may escape, and often do escape, *invisibly*, from the chimney; and, as they are all combustible, are, strictly speaking, so much loss of fuel. Steam is also an invisible product of combustion, and a constant ingredient of smoke.

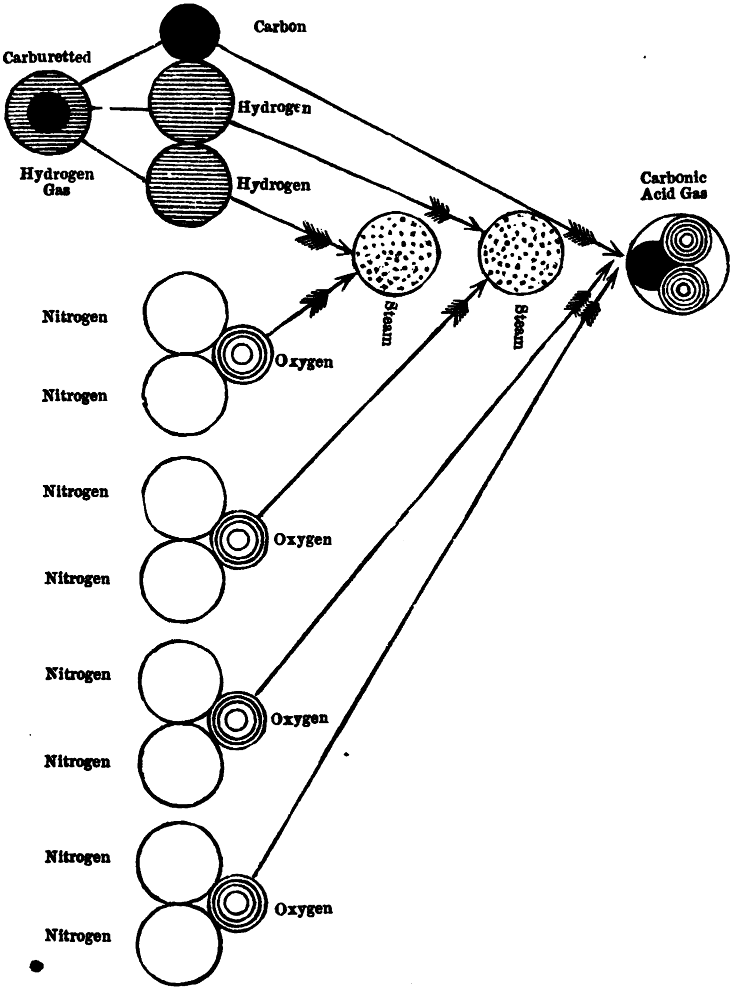
Your system of throwing jets of air into the inflammable gases and vapours which constitute so large a part of the matters which, in many ill-constructed fire-places and furnaces, escape by the chimney along with the finely-divided carbon, or *black smoke*, renders them all available as sources of heat; and where that system is perfectly applied, the *smoke* can consist of very little else than carbonic acid, steam, and nitrogen; all *incombustible*, and also incapable of *supporting* combustion.

Yours, my dear Sir, very faithfully,

WILLIAM THOMAS BRANDE.

C. W. Williams, Esq., Liverpool.

Fig. 141.


Carbon
Carburetted
Hydrogen
Hydrogen
Hydrogen
Gas
Carbonic
Acid Gas
Steam
Steam
Nitrogen
Oxygen
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Oxygen
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Nitrogen
Oxygen
Nitrogen
Nitrogen
Oxygen
Nitrogen

APPENDIX.

REMARKS ON THE FOREGOING MODE OF EFFECTING THE COMBUSTION OF COAL IN FURNACES.

REMARKS BY MR. BRANDE.

Royal Mint, London, 26th November, 1840.

My dear Sir, — I am convinced, that you are not only practically, but theoretically and scientifically, right in regard to the general views put forth in your Essay on the Combustion of Coal and the Prevention of Smoke. I have long advocated the principles which you have adopted, and have annually illustrated them in my lectures in the Royal Institution; but it unfortunately so happens, that when *scientific* men urge new views, or suggest the practical adoption of rational theories, they are neglected, because it is presumed they are merely founded on unsubstantial hypotheses; and, on the other hand, when *practical* men attempt to found improvement on scientific principles, they are sneered at as dabblers in science; and so, both become disheartened and disgusted, and the only people who are temporarily successful are *quacks*, who, pretending to what is called originality, and, neither referring to practice or science, steal from both; but, deficient in all knowledge of their own, ultimately mislead their followers; and, like the alchemists of old, not unfrequently deceive themselves.

Under these circumstances, it is really refreshing to find a person of your experience willing and able to blend practice with science and theory; and I have no hesitation in saying, that the views promulgated in your Essay are substantially founded upon just and scientific principles.

When the unburned hydrocarbons, which are produced during what is commonly called the *combustion*, but which, in reality, is principally the *destructive distillation* of coal, in our ordinary steam-boiler furnaces, gradually mix with air, they assume the form of what is called uninflammable smoke; but, if they be examined *immediately after* they leave the fuel and *before* they have blended with excess of cold air in the chimney shaft, they are found to be highly inflammable and rich in carbon. *At this point* it is that you judiciously admit the jets of air; and in so doing, every jet that enters the inflammable atmosphere within the flues becomes, as it were, the centre of combustion, and tends to increase the heat, by burning and destroying that hydrocarbon, which otherwise would go on to produce worse than useless smoke.

I have now given you my candid opinion respecting your views of the phenomena of combustion and their application to the object proposed in your Essay: there are some of the minor points of which I cannot speak without further consideration; but these do not, in any way, affect the main object of the inquiry in its practical bearings.

I am always, my dear Sir, sincerely yours,

WILLIAM THOMAS BRANDE.

To Charles W. Williams, Esq.,
Dublin Steam Packet Company, Liverpool.

REMARKS BY ANDREW URE, M.D., F.R.S.

Having now carefully perused your treatise " On the Combustion of Coals and the Prevention of Smoke, Chemically and Practically considered," I cannot help congratulating you on the manner in which you have studied the phenomena of a furnace — phenomena which, like those of the freezing and boiling of water, had been for ages exhibited to the eyes of the philosopher and the engineer, without receiving from the one a scientific analysis, or leading the other to any radical improvement. You have fully demonstrated the defectiveness and fallacy of the ideas generally entertained concerning the operation of fuel in furnaces, and the errors, consequently, committed in their construction.

You will remember, that when, about ten months ago, you laid before me the first draught of the specification of your patent furnace, with what delight I hailed your invention as the harbinger of a brighter day for steam navigation, where economy of fuel has become the *sine quâ non* in regard to long voyages. I rejoice that, with the ample means placed at your command, you have since prosecuted the subject, through all its ambiguities, to a clear and conclusive demonstration of the efficacy of your plan for calling forth from pitcoal all its dormant fire, and diffusing it most efficaciously over the surfaces of boilers and along the flues. I am more particularly pleased with your analysis of the combustion of the gases and vapours given out by hydrogenous coal, commonly, though incorrectly, called bituminous, for it contains no ready formed bitumen, but merely its elements, carbon, hydrogen, and oxygen.

Every coal which contains much hydrogen, and therefore, loses much weight by ignition in retorts, necessarily produces much smoke, with a great waste of heat in our common steam boiler furnaces, for reasons which you have so well developed in your treatise. " When a carburetted hydrogen," says Leibig, " is kindled, and just as much oxygen admitted to it as will consume its hydrogen, the carbon does not burn at all, but is deposited (or separated) in the form of soot; if the quantity of oxygen is not sufficient to burn even all the hydrogen, carburets of hydrogen are produced poorer in hydrogen than the original carburetted hydrogen."

A coal which, like the Newcastle caking coal, contains 5·239 of hydrogen, is capable of giving out in complete combustion as much heat as if it contained an extra 10½ per cent. of carbon; but, instead of this additional heat, it affords in common furnaces much less heat than the Llangennock, though this is much poorer in the most calorific constituent, viz., the hydrogen.

In the case of great steam-boiler furnaces, for which your patent is especially intended, since these are fed at short intervals, your plan of distributing atmospheric air, in a regulated quantity, by numerous jets, through the body of the gasiform matter, is peculiarly happy, and must enable you to extract the whole heat that the combustible is capable of affording. The method also which you have contrived for distributing the air under the surface of the grate will ensure due combustion of the coked coals lying there, without admitting a refrigerating blast to the fire. And, finally, your mode of supplying atmospherical oxygen will prevent the possibility of the carbon of the coals escaping in the state of carbonic oxide gas, whereby, at present, much heat is lost in our great furnaces.

ANDREW URE.

13, Charlotte-street, Bedford-square, London,
December 26, 1840.

REMARKS BY DR. BRETT.

Laboratory, Royal Institution, Liverpool, Jan. 6, 1841.

I now take the opportunity of expressing more fully my opinion of your views concerning the combustion of coal and prevention of smoke, and it gives me the greater satisfaction so to do, in consequence of having enjoyed, on more than one occasion, an opportunity of examining, in your experimental furnace, when in operation, the different stages of coal combustion. Your furnace being so constructed that it allows of a close inspection of the changes which take place within the flue, behind the bridge, no person, however imperfectly acquainted with those scientific principles upon which combustion ought to be effected, can avoid recognizing the great difference (a difference sufficiently palpable to the sight) which exists between combustion, as conducted in furnaces upon the old plan, and that which takes place in yours, when the inflammable matters receive *good air properly supplied.*

Every one who observes the volumes of black smoke escaping from the chimneys of manufactories must be struck with the positive loss of fuel thus sustained; yet, not only is the black smoke lost for calorific effect, but a further loss may be traced to the passing off of what may be called a smoke, though not visible — I mean unburnt carburetted hydrogen and carbonic oxide. You have been fully alive to the truth of this; and, by a felicitous contrivance, have shewn, that, by mingling atmospheric air with the inflammable gas, before they can escape unburnt, black smoke may be got rid of, or, in other words, that loss of fuel and consequent loss of heat may be avoided.

On one occasion whilst watching the process of combustion, during its different stages, in your experimental furnace, at that period when the hydrocarbons had just undergone combustion, and the carbonaceous matter, or coke, was remaining on the fire-bars, highly ignited, I observed, when looking into the flue, the phenomenon of a peach-coloured flame mingled with one of a striking blue colour. The former I believe to be produced by the burning of cyanogen: the latter was undoubtedly due to carbonic oxide. To the interesting fact of the combustion of the latter gas, after that of the hydro-carbons, you will remember to have directed my attention on a former occasion. I need hardly say, that without a proper supply of atmospheric air, these gases would have escaped by the chimney, and so have been lost for calorific purposes.

By causing atmospheric air to be driven *by jets* among the inflammable gases, you employ, as it appears to me, the only means practicable, in operations on a large scale, of causing a sufficient mechanical admixture between the air and the gases to be burnt. By such means, too, you considerably extend the surface of any given bulk of atmospheric air admitted, in the same way as the surface of any given volume of water is greatly increased by causing it to pass, in thin streams, through a vessel containing numerous apertures.

On the whole, then, I would observe, that your treatise is correct as to its theoretical and scientific principles; and by your illustrations on the large scale of the furnace, you have demonstrated how science and practice may be made to harmonize, and have shewn the importance of attending, strictly, to the *chemical* conditions on which combustion takes place, without which all must be error and uncertainty.

R. H. BRETT, Ph. D., F.L.S.

To C. W. Williams, Esq.

REMARKS BY DR. ROBERT KANE.

Royal Dublin Society, January 16th, 1841.

DEAR SIR, — I received the copy of your work and the other papers illustrative of your views of the nature of combustion and of the construction of furnaces, and I consider your suggestions as being of peculiar value, inasmuch as they indicate to the engineer and mechanist the principles on which alone the perfect combustion of fuel can be secured. They serve also as an additional proof, were such wanted, that complete success in art — the greatest economy in materials—and the most perfect utilization of its products, can only occur when the *scientific* conditions of the process are clearly understood and made the *foundations of practice*.

In your furnace alone, of all the plans I have had an opportunity of examining, the conditions for the complete combustion of *all* the constituents of the fuel, are secured in the proper circumstances of *quantity, time,* and *place.*

The introduction of air at the bridge and along the flame-bed, to supply the quantity of oxygen necessary for the combustion of the volatile products of the coal; — the diffusion of this air, secured by its issuing from a great number of small jets, and the consequent full combustion of the gaseous fuel before it leaves the surface of contact with the boiler, are elements of real economy and success in practice. The value of this, although, perhaps, obscurely felt by others, from the imperfection of the older methods, has been, certainly, first placed in its important and just aspect by your illustrations.

The formation of *carbonic oxide* in furnaces, to which I find, in your work, *for the first time, the attention of practical men directed,* has, hitherto, been a source of loss of fuel to a very considerable extent. When carbonic *acid* streams over a surface of ignited charcoal, or coke, it cannot be considered to evolve heat in taking up an additional equivalent of carbon. This is verified by the fact, that the carbonic oxide thus formed gives out, in burning, only the same quantity of heat which the second equivalent of carbon should have given out if it had formed *carbonic acid directly.*

This heat you encourage, and hence, even at those periods when carbonic oxide is produced, you lose no fuel, whereas, in all the ordinary plans of avoiding *visible smoke,* the fuel is evolved in carbonic oxide, and is either silently escaping as *invisible* gas, or burns at the orifice of the chimney, wasting there the carbon which should have been economized below.

I like the plan of your diagrams very much. In popular use, and especially, for the instruction of those who have not made abstract calculations their study, they are exceedingly valuable: so much so, that our illustrious and venerable friend, Dr. Dalton, the Nestor of the physical sciences, as he has been termed by Dumas, proposed a plan not unlike yours, but which, from the very fact of its being more adapted to class illustrations than to the calculations by symbols, (now so necessary in scientific chemistry,) was kept very much out of view, lately, by the employment of the Berzelian notation. When one writes, as you do, not merely for those who know a good deal, but for those who are not used to the kinds of ideas you wish to communicate, every adjunct which tends to awaken the senses to the subject is of the highest importance.

In conclusion, I beg to express my conviction, that, by giving to the scientific world the true philosophy of combustion upon the large scale of the furnace, and indicating to the mechanist the conditions upon which the proper construction of furnaces must rest, you have illustrated, remarkably, the value of science applied to the useful arts, and have effected considerable service to the public.

Believe me, my dear Sir,
Sincerely yours,
ROBERT KANE.

To C. W. Williams, Esq.

The following Letters are important, as they refer to the Furnace mentioned in the Letter of the Earl of Ellesmere. (See Note, Chapter V.)

32, Moorgate Street, London,
26th July, 1854.

C. W. Williams, Esq.

Dear Sir,—Considering it might be interesting to you and the public, to be assured of long continued success in the application of your Principle of Smoke Prevention, I have recently communicated with Messrs. Lockett, of Manchester, at whose works I commenced operations, and I have much pleasure in forwarding you their reply. I could have supplied numerous similar letters, of early date, from eminent engineers, manufacturers, and others, were further confirmation at all requisite. I have superintended the erection of above 2000 Argand Furnaces, of all descriptions, and continue erecting them, for every class of work.

I am, your obedient servant,
HENRY DIRCKS.

Strangeways, Manchester,
25th July, 1854.

Messrs. Dircks & Co.,
32, Moorgate Street, London.

Gentlemen,—In reply to your inquiry respecting the Patent Argand Furnace of Mr. Charles Wye Williams, erected by you at our Works in 1840, we have great pleasure in assuring you, that in regard to Smoke Prevention, it is most satisfactory, and we can speak confidently, that there is a considerable saving in fuel. We have had the patent plan applied to three different boilers since we first adopted it, and in each case with the same satisfactory result. There cannot be the smallest doubt, that the principle of Mr. Williams's plan, is that on which the prevention of smoke can alone be effected, whatever may be the mode of applying it.

We remain, Gentlemen,
Yours very respectfully,
(Signed) JOSEPH & JAS. LOCKETT & CO.

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Details of ditto: transverse section through working gear, transverse section and end view of tender; plan and section of feed-pump; plan and elevation of hand-pump; details of inside framing, centre axle, driving axle-box, regulation valve, centre-beam stay, &c.
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Ditto, drawn and engraved to half-size: fig. 1, old valve, $\frac{1}{16}$-inch lap; fig. 2, $\frac{3}{8}$-inch lap; fig. 3, $\frac{3}{4}$-inch lap; fig. 4, $\frac{7}{8}$-inch lap, Gray's patent; fig. 5, 1-inch lap.
Elevation of a six-wheeled locomotive engine and tender, No. 15, constructed by Messrs. Tayleur, Vulcan Foundry, Warrington, for the Caledonian Railway.
Longitudinal section of ditto.

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